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Innovative Design Strategies to Reduce EMF Pollution from the Indoor Environment

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ABSTRACT

Electromagnetic fields (EMF) are all around in the built environment in different forms and come from a number of sources including electrical wiring and devices, wireless communication, and energy-efficient lights, devices, and appliances. It can radiate into the indoor environment directly from indoor sources, or can be transmitted through building materials from outside sources. Scientists have identified it as an indoor environmental pollutant or toxin that has ubiquitously plagued developed nations causing a variety of adverse health effects such as sick-building syndrome symptoms, asthma, diabetes, multiple sclerosis, leukemia, electro-hypersensitivity (EHS), behavior disorders, and more. Scientific studies have suggested that the increased demand for electricity and wireless communication is a global phenomena causing harm not only to the environment but also to health. Unfortunately, there is currently no international consensus on guidelines and exposure limits.

Based on thousands of epidemiological and laboratory studies, many international governments and organizations have adopted the *prudent avoidance principal* or *precautionary principal* until a firm scientific link between EMF and disease is established. The policy of prudent avoidance is a precautionary principal to reduce potential risk to the general public through reasonable efforts and can vary among countries, governments, and local authorities as to the extent of action to be taken. In Canada, there are no standard EMF exposure limits for everyday home or office electronics and appliances; however, Safety Code 6 produced at the federal government level, provides exposure limits for radiowaves. In 2008, the Greater Toronto Authority (GTA) adopted the policy of prudent avoidance to reduce childhood exposure to power frequency EMF in and adjacent to hydro corridors only. Thus, the focus of this research is to extend the prudent avoidance principal in residential construction by developing and implementing design strategies to reduce EMF pollution through low-cost or no-cost measures. The design strategies have been implemented in the renovation of a1909, three-storey, single family dwelling, as part of Renovation 2050 – a sustainable renovation initiative located in Toronto, Ontario.

This paper presents the analysis of the integrated design process in developing a sustainable, energy-efficient house, while creating a high quality, healthy, indoor environment. Results indicate that careful design and selection of building envelope materials, lighting, HVAC system, and electrical wiring and configuration, not only can potentially reduce energy consumption but also significantly reduce exposure to EMF pollution.

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1.1 Overview of Problem

Electromagnetic energy are electromagnetic fields which are commonly referred to as EMF. EMF exposure is complex and unavoidable in the built environment as it comes in different forms of energy from a number of sources including electrical wiring and devices, wireless communication, and energy-efficient lights, devices, and appliances. It can radiate into the indoor environment directly from indoor sources, or can be transmitted or conducted through building materials from outside sources. Scientists have identified it as an indoor environmental pollutant or toxin that has ubiquitously plagued developed nations causing a variety of adverse health effects similar to sick-building syndrome symptoms such as asthma, diabetes, multiple sclerosis, leukemia, electro-hypersensitivity (EHS), behavior disorders, and more (Genuis, 2007).

Scientific studies have suggested that the increased demand for electricity and wireless communication is a global phenomena causing harm not only to the environment but also to health. Today EMF pollution can be defined as exposure to electricity, radiowaves, and poor quality power commonly referred to as "dirty electricity" which is the distortion of clean electricity with higher frequency electromagnetic energy. EMF from electricity is referred to as low frequency EMF or power frequency; EMF from radiowaves is referred to as radio frequency radiation or electromagnetic radiation (EMR). In this report, EMF will be referred to as power frequency, and EMR will be referred to radio frequency radiation. Unfortunately, there is no international consensus on guidelines and exposure limits. In the absence of guidelines, the most commonly cited and referenced guidelines and exposure limits was developed by International Commission on Non-Ionizing Radiation (INCIRP, 1998; INCIRP draft revision, 2009).

Historically, a peak in childhood leukemia for ages 2 to 4, emerged in the 1920's in the United Kingdom and slightly later in the United States (Milham and Ossiander, 2001). In the US, between 1928 and 1951, the peak in childhood leukemia mortality increased 24% for ages 2 to 4 for a 10% increase in percent of homes served by electricity (Milham and Ossiander, 2001). Leukemia has also been associated in adults exposed to high levels of EMF. Several studies have found that occupations with a higher EMF exposure had increased mortality due to leukemia (Milham, S., 1982, 1988, and 1996).

In North America, the first research study that correlated residential high-current electrical wiring configuration with childhood leukemia sparked international concern. Immediately, the scientific community and the public demanded the scientific mechanism driving the observed correlation

(Wertheimer-Leeper, 1979). This study is considered the starting point for all research in this field. The main conclusion of the study found a strong correlation between affected children who had died of cancer and visible electric wiring at their houses. Further, non-cancer comparison houses did not contain visible electrical wiring. The resulting difference between the two study groups being higher electric currents which resulted in higher magnetic fields. It was later replicated in a study with similar findings (Savitz, 1988). The researchers found that families with young children made different house choices than older families which resulted in older affordable areas with high wire configuration codes (HWC) (but sometimes low wire configuration codes (LWC)) that distinguished between thick and thin primary wires and open or spun secondary wires which differed from newer developments with buried power lines and reduced EMF (Wertheimer-Leeper, 1994). The same researchers later found an association with adult cancer and high-current electrical wires near the affected person's residences (Wertheimer-Leeper, 1982 and 1994). They also found an association of poor fetal development resulting in fetal loss when mothers were exposed to heated water beds or electric blankets that produced about 15 mG (milligauss) magnetic fields (Wertheimer-Leeper, 1986 and 1989). It should be noted that some studies have found a poor correlation between high electric fields with high magnetic fields unless the homes are located near larger transmission lies (Kheifets, 2010).

During the 1970's, utility companies were also addressing issues related to harmonic distortion on electrical power lines which are caused by high frequency radiowaves riding along the power lines and into buildings causing overheating of neutral conductors, cables, and electronic interference (Havas, 2007). Harmonic distortion is generated by non-linear loads such as computers, plasma televisions, energy efficient appliances, energy efficient lighting (i.e. compact fluorescent bulbs), transformer based dimmer switches, as well as arching on electrical conductors caused by loose wires (Havas, 2006). In recent years, scientists have labeled harmonic distortion as "dirty electricity" or "poor quality power" (Havas, 2006). Studies have reported a high correlation between dirty electricity and symptoms resembling 'sick-building syndrome' in addition to illnesses such as diabetes, multiple sclerosis, asthma, ADD, and electrical hypersensitivity (Havas, 2004, 2006, 2008); Havas and Stetzer, 2004). Other studies have identified a correlation between dirty electricity and reduced milk production of cows (Stetzer and Graham, 2002; Hillman et al., 2002).

With increased demand for wireless communication, high-frequency data communication antennas are more commonly being installed on transmission lines as a supporting structure (Figure 1.1).

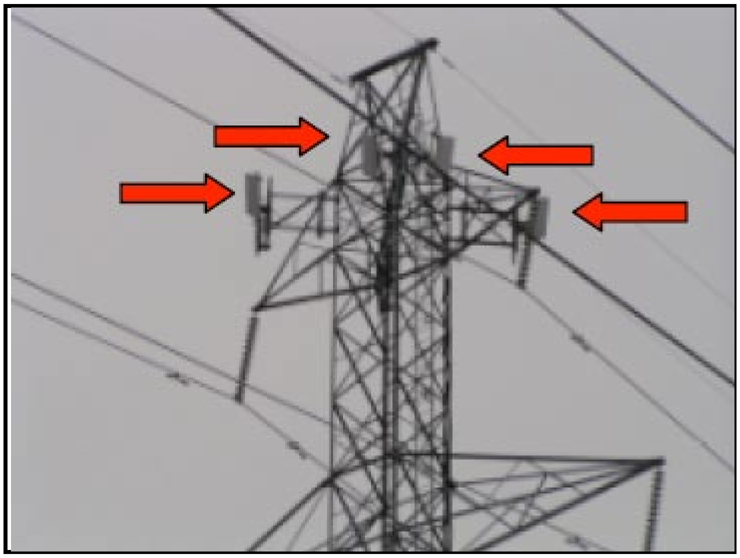

Figure 1.1: Cell phone antennae’s on power lines in Ontario (Source: Havas, 2007).

Power lines were intended to distribute the 60 Hz power frequency, but now these high radio frequencies are riding along the power lines causing increased dirty electricity contributing to poor quality power. The studies show that poor quality power in the frequency range of 4 kHz to 100 kHz (4000 Hz to 100,000 Hz) on indoor wires effects health (Havas, 2007).

One study on power lines with data communication installed detected radio frequency currents (112 to 370 kHz) on the 60Hz power lines (Vignati and Guiliani, 1997). Several epidemiological studies of people who live near cell phone antennas (within 300 meters) have been conducted with similar results all showing an increased risk of cancer (Naila, 2004), or, of symptoms of electrohypersensitivity (EHS) (Santini et al. 2001, Navarro et al, 2003). The studies reported increased symptoms such as: fatigue, sleep disturbances, headaches, and feeling of discomfort, difficulty concentrating, depression, memory loss, irritability, hearing dysfunctions, cardiovascular disorders, and dizziness.

Since these early studies by Wertheimer and Leeper, thousands of epidemiologic and laboratory studies have been published, but there has been no strong evidence linking low-frequency EMF with cancer based on the epidemiologic studies (NRC 1995, FPTRPC 2005). On the other hand, biological studies show definite biological effects on humans and other living organisms (Habash, 2002). Electricity is supplied by wires into buildings which also transports the dirty electricity throughout buildings. The combination of power frequency and higher frequencies has not only proven to cause electromagnetic interference (EMI), but also serious health problems resembling ‘radio wave sickness’ and/or ‘sick building syndrome’[Firstenberg, 2001].

Electrical hypersensitivity (EHS), also called electrosensitivity, has been recognized as an illness in some people reacting to electrical pollution (Johansson, 2006). A study done on dirty electricity suggests that EHS could be affecting the lives of millions of people all over the world, particularly in developed countries (Havas, 2004). In some cases, it has been found that people experiencing EHS have similar skin damage to those who get skin damage from ultraviolet light (or ionizing radiation) when exposed to electronics such as video display terminals (Johansson, 2006). Symptoms include skin redness, eczema and sweating, loss of memory, concentration difficulties, sleep disturbances, dizziness, muscular and joint-related pain, headache, faintness, nose blockage, and fatigue – all EHS people experienced tinnitus (Johansson, 2006).

EHS can occur from exposure to low frequency electric fields and/or dirty electricity. Numerous studies found that the installation of Graham/Stetzer (GS) filters in homes and schools improve occupant health and well-being by reducing the harmonic distortion (Havas and Olstad, 2008; Genuis, 2007; Havas, 2006; Havas and Stetzer, 2004).

The increased public awareness of EMF pollution and dirty electricity being associated with illnesses has sparked international organizations to develop voluntary standards and guidelines (ICNIRP, 1994; ICNIRP Draft Revision, 2009). Based on thousands of epidemiological and laboratory studies, many international and national agencies are adopting the 'precautionary principle', or, 'prudent avoidance principal' until a firm scientific link for both EMF and EMR with disease is established (Havas 2007). The policy of prudent avoidance is a precautionary principal to reduce potential risk to the general public through reasonable efforts without waiting for full scientific certainty. Without postponing cost-effective measures to prevent risk, countries and local authorities around the world have started to take action, but the level of action varies from country to country. In 2008, the Greater Toronto Authority (GTA) adopted the policy of prudent avoidance to reduce childhood exposure to EMF in and adjacent to hydro corridors only.

Currently in Ontario, there is an increased demand for electricity as development rapidly increases (OPA, 2008). The Ontario Power Authority (OPA) is proposing to develop a new $600 million high-voltage transmission line in east Toronto that will require new 10 storey-high hydro pylons extending from Victoria Park and Steeles Ave. into the downtown core. The OPA has predicted that the GTA will demand 15% more electricity by the year 2025. The output from the Bruce or Darlington Nuclear Generating Stations will have to expand to meet this demand, and therefore, the need for a new transmission line. It has been recommended by the Ontario Clean Air Alliance as an alternative to promote an integration of energy conservation and efficiency, new renewable and natural gas-fired combination heat and power plants. This would provide a more efficient electricity system, better air quality, and reduced global warming. The bigger problem of his proposal is that it will increase EMF exposure to neighbouring buildings.

There are six transmission companies in Ontario that are licensed and regulated by the Ontario Energy Board to supply this energy: Hydro One; Great Lakes Power; Canadian Niagara Power; Five Nations Energy; Cat Lake Power Utility Limited; Niagara West Transformation Corporation; a seventh transmission company, Cedars Rapids Transmission, is not connected to the Provincial Power grid and is not required to be regulated by the Board.

At present, all of the power consumed in Toronto is generated outside the city. Under peak conditions, the capacity of the transmission wires is not sufficient to meet demand. Part of the solution is new local generation supply, from the Portlands Energy Centre, currently being built on Toronto's waterfront. Completion of the John Transformer Station (TS) to Esplanade TS link by Hydro One is suppose to enhance reliability to central Toronto by increasing the capability to transfer some loads from their normal supply east of the city, to an alternate supply from the west, and vice versa.

With the proposed transmission line expansion, the prudent avoidance principal will require distancing the transmission line a minimum 300 feet from occupied buildings and residences. Gas-fired electricity is predominant in the GTA with 115, 230, and 500 kV transmission lines. The map on the next page shows the location of transmission stations and transmission lines (Figure 1.2):

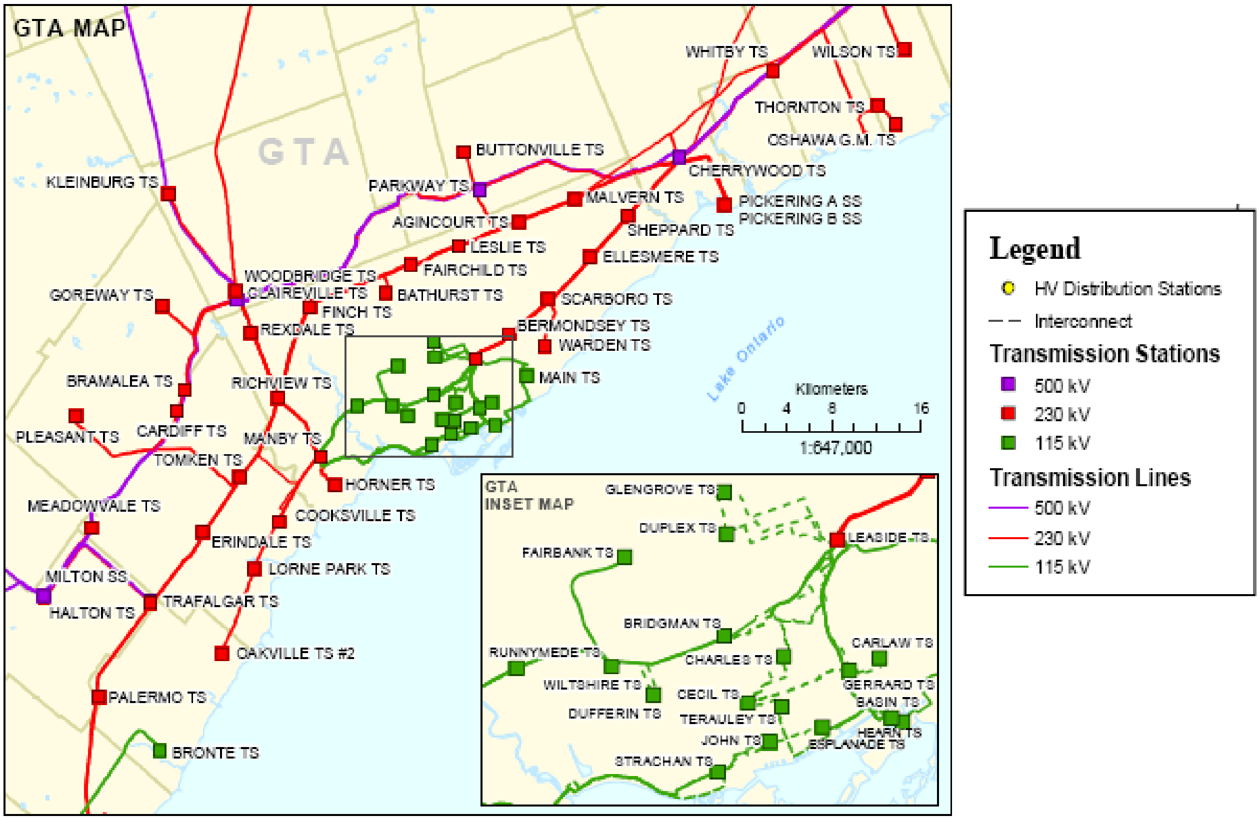

Figure 1.2: Map of Ontario transmission lines and generation plants (www.hydroone.com).

For building occupants, reducing electricity consumption and using appropriate energy-efficient appliances and devices is critical in reducing EMF pollution. However, those involved in the generation, distribution, and safety of power-frequency in Ontario should be responsible in ensuring clean electricity in buildings. These organizations include:

1. **Electrical Safety Authority:** who are responsible for public electrical safety in Ontario including enforcement of the Electrical Distribution Safety regulation 22/04.
2. **Local Distribution Company:** takes power from high-voltage transmission lines, “step down” the electricity to a low voltage level (50KV and under), and provides it to local customers of all sorts: homes, school, stores and factories.
3. **Hydro One:** manages and maintains Ontario’s high-voltage transmission system, and provides electricity directly to a number of customers as a Local Distribution Company. In addition, they provide electrical safety information; information about the provincial high-voltage electricity system; and information about the low-voltage distribution system.
4. **Electricity Distribution Association:** represents local distributors of electricity and provides information to the public about the electrical distribution system.

The joint effort of the above organizations and building occupants can significantly reduce EMF exposure and potentially improve and/or enhance the quality of life for most Canadians.

Today, there are a few EMF consultants in the industry, some are professional engineers, electricians, and some who have entered this field due to their own personal illnesses from exposure to EMF. Currently, there are no known building science professionals working in this field. With the current scientific knowledge available, it is highly recommended that building industry professionals adopt the prudent avoidance principal and take the lead in reducing potential harmful EMF exposure to the general public with the objective in creating a superior healthy indoor environment.

1.2 Objective

The primary objective of this MRP is to develop strategies to reduce EMF pollution in the indoor environment and implement the strategies in the renovation of a single-family model prototype house, in accordance with the prudent avoidance policy being strategies that are either low-cost or no-cost. The secondary objective is to use this model house to educate industry professionals on EMF pollution issues and how they can apply the design strategies for new development or restoration of low-rise residential buildings for a superior indoor environment.

1.3 Methodology

The methodology in achieving the objectives are as follows:

1. Research and understand the issues related to EMF pollution that originate from a number of sources from our built environment through an extensive review of the scientific literature available during this study, conducting interviews with industry experts, and attend available lectures in this field, in order to establish benchmarks for testing and develop design solutions.
2. Design innovative strategies to reduce EMF pollution within the indoor environment in accordance with the ‘prudent avoidance principal’ being low-cost or no-cost solutions and integrate the strategies with a high performance, energy-efficient building design.
3. Construct and implement the design strategies in a renovation project of a 1909, three-storey, single-family dwelling, located in Toronto, Ontario, to be completed in fall 2010.
4. Test and measure EMF pollution levels before, during, and after the renovation using scientific measuring equipment. Also test and measure EMF pollution from neighbouring single-family dwelling units for comparison to our renovation.
5. Analyze the results and performance of the design and draw conclusions in a final report.

1.4 Scope of Work

The research and solutions presented in this MRP is relevant to all types of buildings, however, the focus is on single-family dwellings in cold climates. The outcome of this research is to provide industry professionals informative information and knowledge that could be extended beyond the residential sector.

1.5 Impact of Research

The global demand for electricity has continuously increased for power and/or heat, combined with rapid wireless technological development, which has resulted in increased building occupant exposure to a variety of EMF pollution sources than ever before in history. Today engineers and other industry professionals are investigating more energy efficient building solutions to reduce their environmental impact and slow down global warming through innovative new technology. At the same time, other scientists have been struggling over the last half of the century to establish a link between EMF pollution and adverse health effects. Unfortunately, the two areas of research have not been successfully merged and some energy efficient solutions are creating higher levels of EMF pollution. Therefore, this research is intended to bridge the gap between energy efficient building design and reducing EMF pollution from the indoor environment.

2 EMF Overview

2.1 Electromagnetic Spectrum

The electromagnetic spectrum is a representation of all electromagnetic energy that is classified into distinct ranges (left to right in Figure 2.1): earth's static geomagnetic fields , extremely low and very low frequencies, radio frequencies, microwave frequencies, infrared, visual spectrum, ultraviolet, X-rays and gamma rays. The classification is based on the characteristics of the electromagnetic energy.

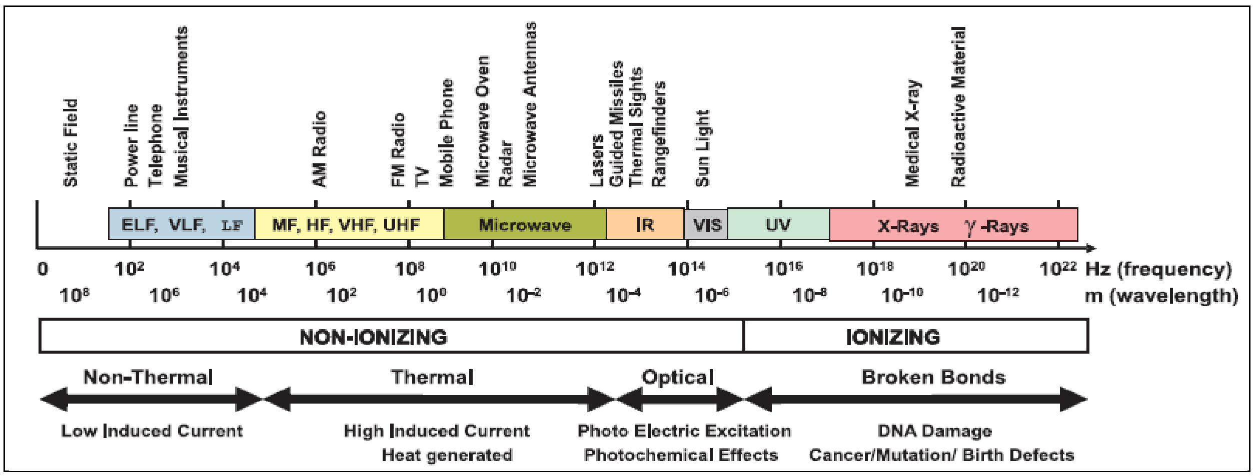

Figure 2.1: Electromagnetic Spectrum (Roe et al., 2008).

Electromagnetic energy are electromagnetic fields (EMF) which are a broad range of invisible three dimensional waves that can be described by its frequency, f, wavelength, λ, and photon energy, E. The frequency can be defined as the number of complete cycles per second measured in hertz (Hz), the wavelength is the distance between the peak on the wave and the next peak on the same polarity and can be measured from kilometers down to nanometers, and the photon energy is directly proportional to the wave frequency. From left to right in Figure 2.1, the electromagnetic fields increases in frequency and energy, while the wavelength reduces in size. In theory, it is considered to be infinite in both directions.

Within the non-ionizing range, EMF is divided into three groups: *non-thermal* EMF which can induce low currents within the body; *thermal* EMF which can induce high currents and generate heat within the body; and the *optical* range which causes photochemical effects (Figure 2.1). Within the ionizing range, the electromagnetic energy is so energized and can be as small as an atom that it can physically alter the atoms as it strikes the cells in the human body changing them into charged particles called ions which are known carcinogens causing cancer, mutation and birth defects. Just as various chemicals affect our health in different ways, various forms of electromagnetic energy can cause different biological effects.

The Standard Letter Designation for Radar-Frequency Bands (IEEE, 2002) was first issued in 1976, revised in 1984, and most current revision in 2002, was written to remove the confusion that developed from the misapplication to radar of letter band designations of other microwave frequency users. This standard relates the letter terms in common usage to the frequency ranges that they represent. The current (2002) revision keeps the same letter band designations, includes a change in the definition of millimeter wave frequencies to conform to the International Telecommunication Union (ITU) Radio Regulations designation (Table 2.1):

ITU Band	Designation	Band Designation Acronyms	Frequency	Wavelength
1	ELF	Extremely Low Frequency	3 - 30 Hz	100,000 km -10,000 km
2	SLF	Super Low Frequency	30 - 300 Hz	10,000 km - 1000 km
3	ULF	Ultra Low Frequency	300 - 3000 Hz	1000 km - 100 km
4	VLF	Very Low Frequency	3 - 30 kHz	100 km - 10 km
5	LF	Low Frequency	30 - 300 kHz	10 km - 1 km
6	MF	Medium Frequency	300 - 3000 kHz	1 km - 100 m
7	HF	High Frequency	3 - 30 MHz	100 m - 10 m
8	VHF	Very High Frequency	30 - 300 MHz	10 m - 1 m
9	SHF	Super High Frequency	300 - 3000 MHz	1 m - 10 cm
10	EHF	Extremely High Frequency	3 - 30 GHz	10 cm - 1 cm

Table 2.1: ITU Electromagnetic Spectrum Designation Bands (Industry Canada, 2010).

2.1.1 Natural Geomagnetic Fields

The earth produces natural geomagnetic fields in the form of static fields, similar to the fields generated by DC electricity and does not have a biological effect. The earth's core produces magnetic fields of about 570 mG at ground level and electric fields are produced by air turbulence and other atmospheric activity at about 120 V/m (Habash, 2002). Geomagnetic fault lines are located throughout the planet and the fields produce almost zero frequency at low end of the electromagnetic spectrum (Figure 2.2).

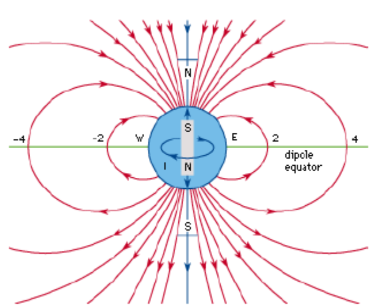

Figure 2.2: Earth's geomagnetic fields (Encyclopedia Britannica, 1994).

2.1.2 Extremely Low-Frequency EMF

Non-ionizing EMF producing no thermal effects in the human body, has low-frequency, low-energy, with a longer wavelength, and falls in the lower (left) range of the electromagnetic spectrum from 0 to 3000 Hz (Figure 2.1). This range can be further divided into more low frequency groups. The designation names can vary, but the frequency range typically is the same. In North America, electricity or power frequency is supplied to buildings within this range at 60 Hz (50 Hz in Europe).

EMF can be further described as being electric and magnetic lines of force, hence the term electromagnetic fields. Within this low frequency band (0 Hz to 3000 Hz), the electric and magnetic fields are two separate lines of force with different characteristics. Electric fields are measured in volts per meter (V/m) and magnetic fields are measured in milligauss (mG). A more detailed discussion can be found in section 2.2.2 of this report.

Most EMF in this band are from man-made sources (Figure 2.3 and 2.4). The following tables lists some common EMF exposures found in the indoor environment.

EMF Exposures in Common Environments
Magnetic fields measured in milligauss (mG)

Environment	Median* exposure	Top 5th percentile	Environment	Median* exposure	Top 5th percentile
OFFICE BUILDING			MACHINE SHOP		
Support staff	0.6	3.7	Machinist	0.4	6.0
Professional	0.5	2.6	Welder	1.1	24.6
Maintenance	0.6	3.8	Engineer	1.0	5.1
Visitor	0.6	2.1	Assembler	0.5	6.4
SCHOOL			Office staff	0.7	4.7
Teacher	0.6	3.3	GROCERY STORE		
Student	0.5	2.9	Cashier	2.7	11.9
Custodian	1.0	4.9	Butcher	2.4	12.8
Administrative staff	1.3	6.9	Office staff	2.1	7.1
HOSPITAL			Customer	1.1	7.7
Patient	0.6	3.6			
Medical staff	0.8	5.6			
Visitor	0.6	2.4			
Maintenance	0.6	5.9			

*The median of four measurements. For this table, the median is the average of the two middle measurements. Source: National Institute for Occupational Safety and Health.

Figure 2.3: EMF exposures in common environments (EMF Rapid, 2002).

Electric fields radiate from high voltage transmission and distribution lines, cables, wiring, outlets, fixtures and switches, electronics and appliances, and coiled beds. The average range within the home is between 0 and 10 volts per meter which is far less than if one stood under a high voltage transmission or distribution line (EMF Rapid, 2002). Electric fields typically reduce 10 to 15 feet away from the source and can be shielded by most building materials and vegetation. Magnetic field exposure radiate from high voltage transmission and distribution lines, overhead and underground cables, appliances, transformers, motors, and railways. Magnetic fields cannot be easily shielded by building materials but reduces drastically within 4 feet from the source. Figure 2.3 and 2.4 lists typical sources of magnetic fields found within the home.

Sources of Magnetic Fields (mG)*

Kitchen Sources	Distance from source 6"	1'	2'	4'
BLENDERS				
Lowest	30	5	–	–
Median	70	10	2	–
Highest	100	20	3	–
CAN OPENERS				
Lowest	500	40	3	–
Median	600	150	20	2
Highest	1500	300	30	4
COFFEE MAKERS				
Lowest	4	–	–	–
Median	7	–	–	–
Highest	10	1	–	–
DISHWASHERS				
Lowest	10	6	2	–
Median	20	10	4	–
Highest	100	30	7	1
FOOD PROCESSORS				
Lowest	20	5	–	–
Median	30	6	2	–
Highest	130	20	3	–
GARBAGE DISPOSALS				
Lowest	60	8	1	–
Median	80	10	2	–
Highest	100	20	3	–
MICROWAVE OVENS* **				
Lowest	100	1	1	–
Median	200	4	10	2
Highest	300	200	30	20
MIXERS				
Lowest	30	5	–	–
Median	100	10	1	–
Highest	600	100	10	–

Kitchen Sources	Distance from source 6"	1'	2'	4'
ELECTRIC OVENS				
Lowest	4	1	–	–
Median	9	4	–	–
Highest	20	5	1	–
ELECTRIC RANGES				
Lowest	20	–	–	–
Median	30	8	2	–
Highest	200	30	9	6
REFRIGERATORS				
Lowest	–	–	–	–
Median	2	2	1	–
Highest	40	20	10	10
TOASTERS				
Lowest	5	–	–	–
Median	10	3	–	–
Highest	20	7	–	–

Bedroom Sources	6"	1'	2'	4'
DIGITAL CLOCK****				
Lowest		–	–	–
Median		1	–	–
High		8	2	1
ANALOG CLOCKS (conventional clockface)****				
Lowest		1	–	–
Median		15	2	–
Highest		30	5	3
BABY MONITOR (unit nearest child)				
Lowest	4	–	–	–
Median	6	1	–	–
Highest	15	2	–	–

Sources of Magnetic Fields (mG)*

Office Sources	Distance from source 6"	1'	2'	4'
AIR CLEANERS				
Lowest	110	20	3	–
Median	180	35	5	1
Highest	250	50	8	2
COPY MACHINES				
Lowest	4	2	1	–
Median	90	20	7	1
Highest	200	40	13	4
FAX MACHINES				
Lowest	4	–	–	–
Median	6	–	–	–
Highest	9	2	–	–
FLUORESCENT LIGHTS				
Lowest	20	–	–	–
Median	40	6	2	–
Highest	100	30	8	4
ELECTRIC PENCIL SHARPENERS				
Lowest	20	8	5	–
Median	200	70	20	2
Highest	300	90	30	30
VIDEO DISPLAY TERMINALS (see page 48) (PCs with color monitors)**				
Lowest	7	2	1	–
Median	14	5	2	–
Highest	20	6	3	–

Bathroom Sources	6"	1'	2'	4'
HAIR DRYERS				
Lowest	1	–	–	–
Median	300	1	–	–
Highest	700	70	10	1
ELECTRIC SHAVERS				
Lowest	4	–	–	–
Median	100	20	–	–
Highest	600	100	10	1

Workshop Sources	Distance from source 6"	1'	2'	4'
BATTERY CHARGERS				
Lowest	3	2	–	–
Median	30	3	–	–
Highest	50	4	–	–
DRILLS				
Lowest	100	20	3	–
Median	150	30	4	–
Highest	200	40	6	–
POWER SAWS				
Lowest	50	9	1	–
Median	200	40	5	–
Highest	1000	300	40	4
ELECTRIC SCREWDRIVERS (while charging)				
Lowest	–	–	–	–
Median	–	–	–	–
Highest	–	–	–	–

Living/Family Room Sources	Distance from source 1'	2'	4'
CEILING FANS			
Lowest	–	–	–
Median	3	–	–
Highest	50	6	1
WINDOW AIR CONDITIONERS			
Lowest	–	–	–
Median	3	1	–
Highest	20	6	4
COLOR TELEVISIONS**			
Lowest	–	–	–
Median	7	2	–
Highest	20	8	4

Figure 2.4: Sources of magnetic fields (mG) within a home (EMF Rapid, 2002).

Direct current (DC) fields were the main power supply for a long time until it changed over to alternating current (AC) fields. DC ‘static’ electric currents flow through a wire in one continuous direction and generally do not induce electric currents in the body since no EMF fields are produced. AC electric currents alternate in direction; this back and forth motion occurs 60 times per second or 60 hertz (60 Hz) in North America (50 Hz in Europe), which produces electric and magnetic fields around the conductor, and exposure can induce electric currents within the body.

2.1.3 Radio Frequency Radiation (RF)

Radio-frequencies are non-ionizing higher frequency electromagnetic radiation (EMR) in the range of 3 kHz to 300 GHz (IEEE, 1995). RF have higher frequencies, higher energy, with a shorter wavelength, and falls in the radio frequency range (middle) of the electromagnetic spectrum (Figure 2.1 and 2.5). This range can be further divided into two groups: radiowaves and microwaves. However, the two groups are typically grouped under radio frequencies.

Within this range, the electric and magnetic waves combine to form electromagnetic radiation (EMR) starting from the non-ionizing radio frequency band up to the ionizing radiation band. The term “EMF” is typically referred to the low-frequency range; however, it is also used to refer to higher frequencies in the radio/microwave range. In Figure 2.5, the wave line to the right illustrates the concept that the higher the frequency, the rapidly the field varies. The fields do not vary at 0 Hz (direct current) and varies trillions of times per second at the top of the spectrum.

Radiowaves are used to transmit data and communication through air space requiring a transmitter on one end and a receiver on the other via modulation. The radio spectrum is subdivided into parts that are used for different radio transmission technologies including AM/FM radio, television, mobile phones, Wi-Fi, and typically allocated by governments. As the demand for wireless communication increases, so is the need for additional communication channels in an already crowded spectrum with most new bandwidth allocations at 12.5 kHz and new allocations at 4.9 GHz (Young, et al, 2010). More discussion can be found in 2.2.3 of this report.

2.1.4 Infrared, Optical, Ultraviolet, X-Rays, Gamma Rays

These higher frequencies are not the focus of this report and will not be discussed in detail.

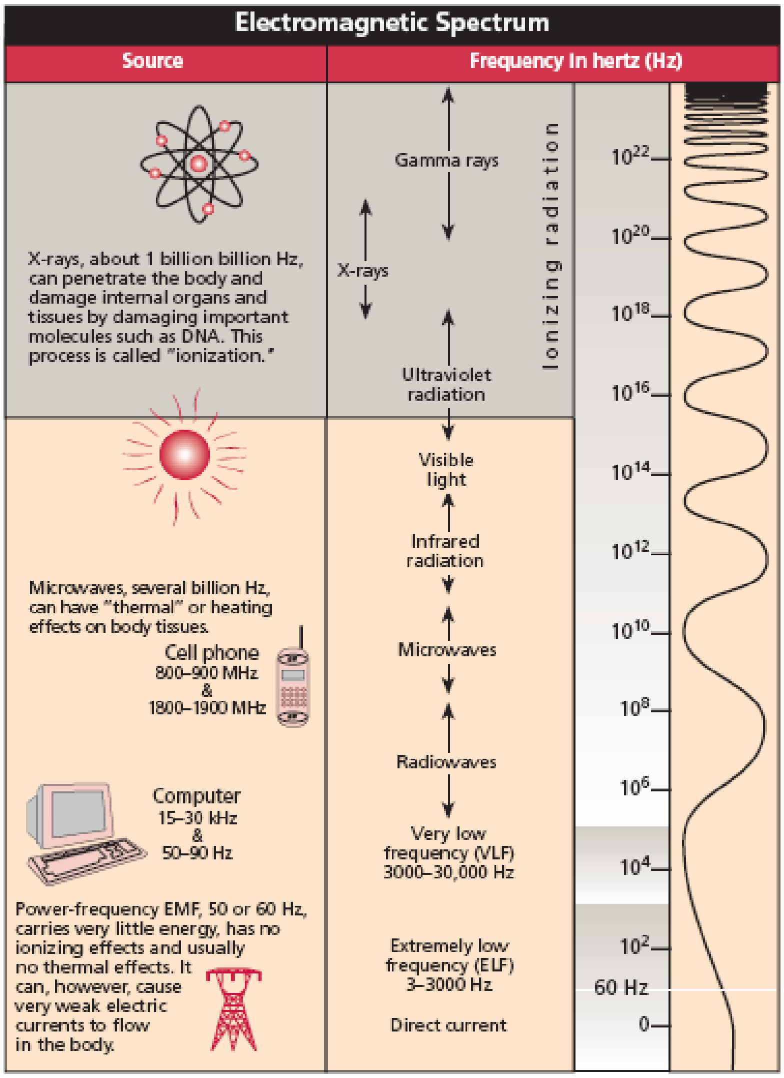

Figure 2.5: Electromagnetic Spectrum (Source: EMF Rapid, 2002).

2.2 EMF Pollutants and Health Effects

The primary focus of this research is on reducing or eliminating occupant exposure to AC power frequency, radio frequency radiation, and dirty electricity due to their potential harmful effects. Identifying and eliminating EMF sources from the indoor environment can be complex since some sources can generate more than one type EMF pollutant. EMF pollutants include:

- Power Frequency
- Ground Current (GC) and Contact Current (CC)
- Radio Frequency Radiation, and
- Dirty Electricity (Poor Quality Power)

Below is a detailed description of EMF pollutants that will be the focus of this research.

2.2.2 Power-Frequency EMF

Electricity in North America is produced at generation plants providing power to our buildings via transmission and distribution lines through underground, aboveground and indoor wiring. The alternating current (AC) electric currents resonate in a back and forth motion occurring 60 times per second or 60 Hz in North America as a perfect ‘clean’ linear sinusoidal waveform from which extremely low electric and magnetic fields are emitted from the wiring (Figure 2.6).

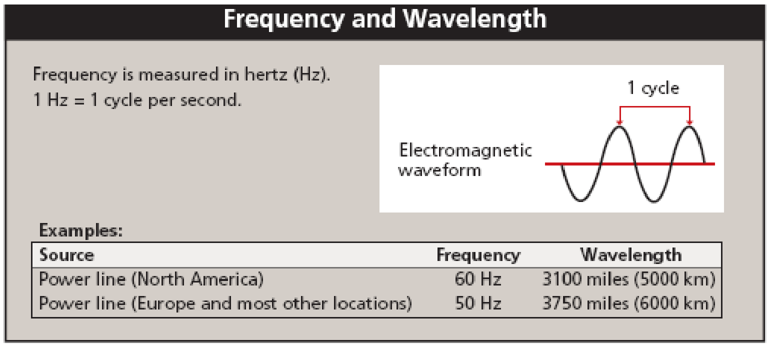

Figure 2.6: Power frequency linear sinusoidal waveform (Source: EMF Rapid, 2002).

Electric fields surround any electrical device such as power lines, electrical wiring, and electrical devices. They also radiate out of electrical outlets, light fixtures and switches. Electric fields are produced by voltage and increase in strength as the voltage increases. Magnetic fields also surround any electrical device resulting from the flow of current through the wires and device. Magnetic fields increase in strength as the current increases. In both cases, the field strength reduces with distance: approximately 4 feet for magnetic fields to almost zero exposure and 10 to 15 feet for electrical fields for a significant reduction (EMF Rapid, 2002). Figure 2.7 below compares the current in a lamp turned off to the water pressure in a hose with the nozzle closed, and when the light is turned on the electricity flows similar to moving water in a hose when the nozzle is opened.

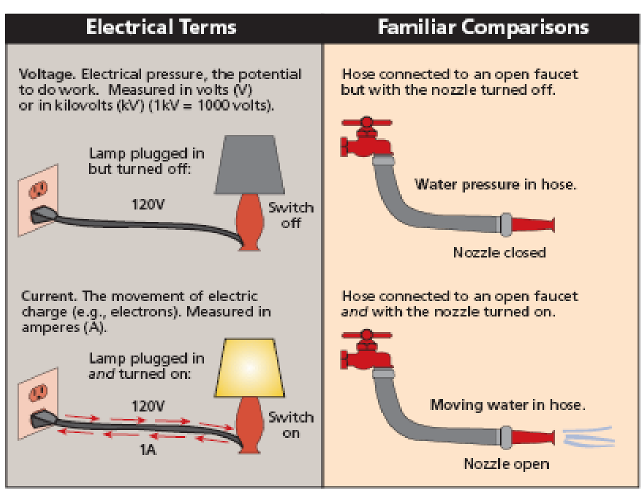

Figure 2.7: Familiar comparisons (Source: EMF Rapid, 2002).

Electric fields are typically measured in volts per meter (V/m) and can be shielded with vegetation and most building materials (EMF Rapid, 2002). Magnetic fields (flux density) are measured in milligauss (mG) or Tesla (T) and is difficult to shield but can be attenuated with absorbing metals such as steel or mumetal (EMF Rapid, 2002). The magnetic field strength is proportional to the current and can be calculated if the amperage is known: twice the current in amperes divided by the distance in meters = the magnetic field strength in milligauss [2i/r=B, where *i* is current in Amps, *r* is distance in meters, and *B* is magnetic field strength] (Riley, 2005).

Figure 2.8 illustrates the difference between electric and magnetic fields. Both are measured in different units, the voltage produces an electric field (left) while the current produces the magnetic field when the device is turned on (right). Both field strength decreases rapidly with distance from the source and electric fields can easily be shielded but magnetic fields are not.

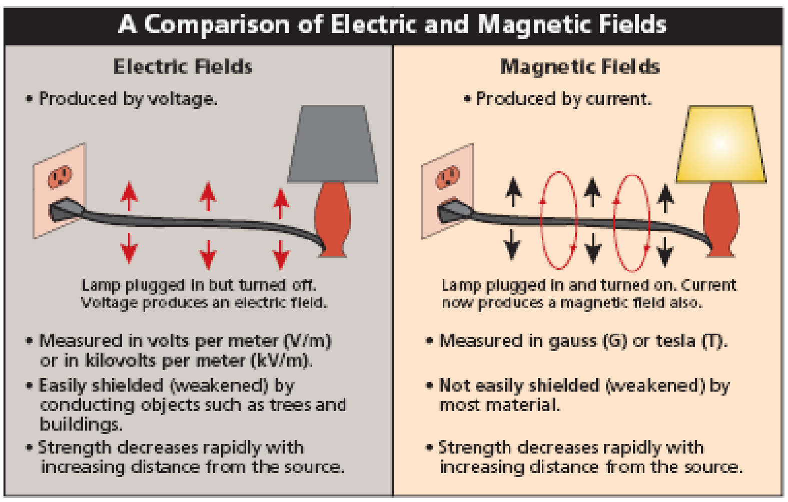

Figure 2.8: Voltage produces an electric field & current produces a magnetic field (Source: EMF Rapid, 2002).

Power frequency EMF pollution is generated from the transmission, distribution, and use of electricity. It is typically found in and around buildings radiating from electrical wiring, outlets, switches, lighting, appliances and electronics. There are several forms of EMF pollution from power-frequency: electric fields, magnetic fields, net current, plumbing current, ground or stray current and dirty electricity.

In residential homes, it has been found that faulty wiring and grounding practices are the main source of elevated levels of magnetic fields (Riley, 2005). Typical "Romex" wiring today contains the live conductor (black), the neutral conductor (white), and a grounding conductor (copper), all within one cable in which the magnetic field is cancelled out as a result of balanced equal currents flowing in opposite directions. The live conductor brings in electric current from the exterior distribution lines and the neutral conductor returns the electric current back to the exterior transformer from where it came from. Figure 2.9 shows the cause of elevated magnetic fields in a survey 150 houses which concluded that wiring and ground problems being the main sources of elevated levels of magnetic fields.

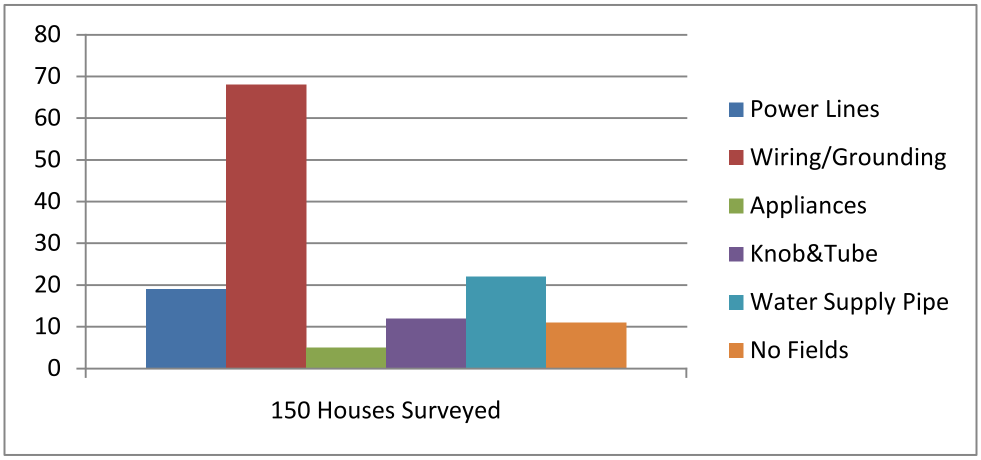

Figure 2.9: Typical sources of high magnetic fields in residential homes (Riley, 2005).

In older homes outdated knob-and-tube wiring emits very high magnetic fields because the live and neutral conductors are usually on adjacent studs or joists and being far apart and the magnetic fields cannot cancel each other. The magnetic field strength between conductors can cause elevated levels of magnetic fields so great that they almost act as a single conductor producing a high field within the enclosed space if the live and neutral conductor comes together as a loop (Riley, 2005). It can be calculated as double the field strength compared with a single net current source [B=4i / d/2, where *B* is milligauss, *i* is amps, and d is distance] (Riley, 2005). Twisting the live and neutral grounding conductors has been used successfully to cancel out the magnetic fields (Riley, 2005). However, the only solution for knob-and-tube wiring is complete removal and upgrade of the electrical system.

Many electronics and appliances contain coil wires which multiply the magnetic field strength in relation to the number of turns, the diameter of the coil, and the amount of current flowing through it (Riley, 2005). The magnetic field strength decreases rapidly by the cube of the distance. Small coil sources drop below one mG at a distance of 18” to 24” and for microwave ovens 5 to 10 feet. Refer to Figure 2.3 and 2.4 for a list of magnetic fields from typical house appliances and devices.

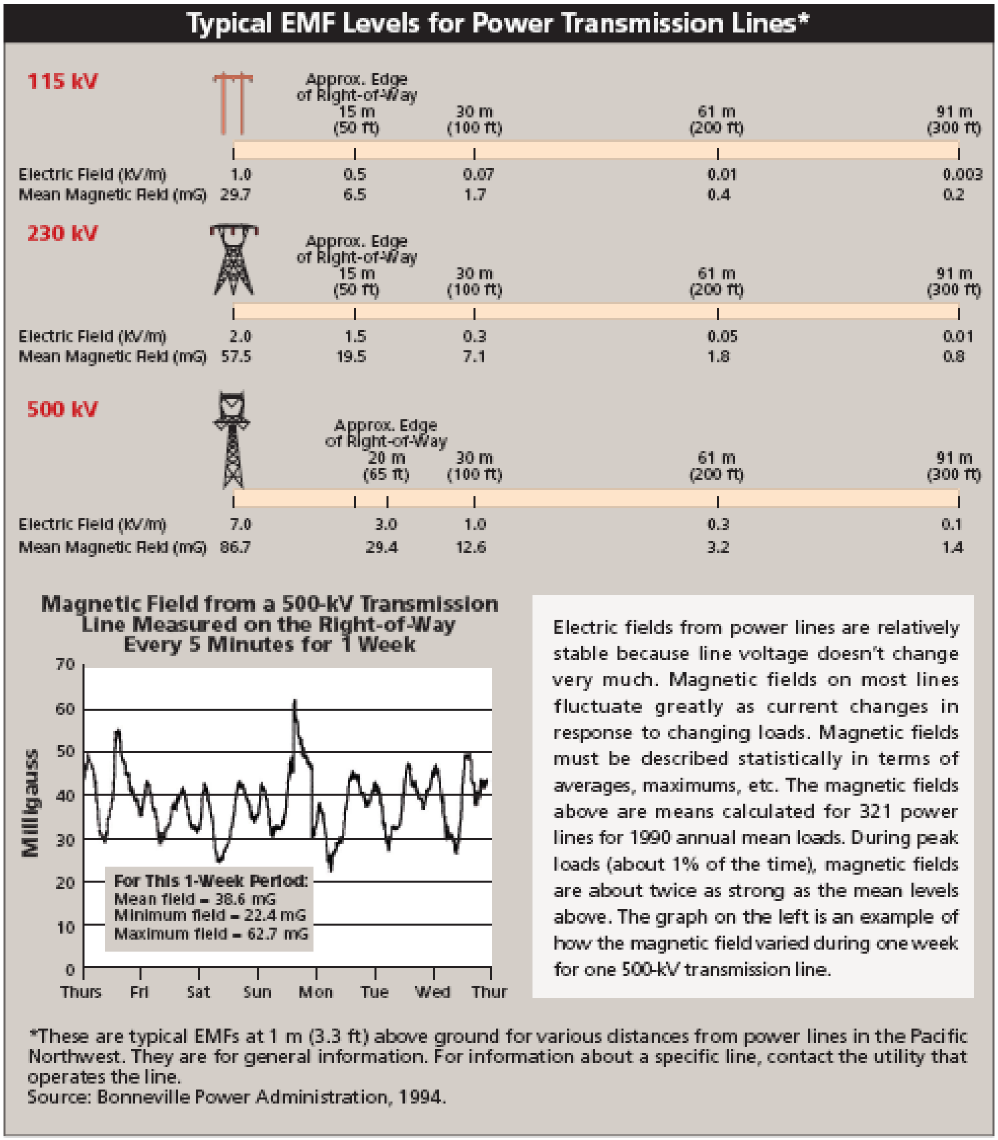

Figure 2.10: Typical EMF levels from power transmission lines (Source: EMF Rapid, 2002).

Overhead and underground power lines will often produce similar levels of electric and magnetic fields on nearby streets and paths, and in some cases the fields from underground cables may be greater for magnetic fields while electric fields are shielded by various screens (EMF Rapid, 2002). Underground power lines will usually produce lower fields at the distance of nearby houses. Transmission lines generate strong electric and magnetic fields, and distribution lines produce weaker electric fields but can generate strong magnetic fields. Pad mount transformers are green metal boxes containing above ground portion of an underground electrical installation. These transform high voltage electricity to low voltage electricity which is then carried in insulated underground power lines into buildings. Figure 2.10 above shows that electric and magnetic field strength significantly reduces 300 feet away from the source depending on the strength of the voltage.

Over the last few decades, much of the attention has been focused on high voltage transmission lines as causing a variety of illness in children and adults. However, prolonged magnetic field exposure from underground transmission, distribution lines, and building wiring can be more significant with comparable field strength levels.

Exposure to both electric and magnetic fields produce biological effects (Habash, 2002). Exposure to low-frequency electric currents and fields, magnetic fields, and very high frequencies (above 100 kHz) can induce electric currents inside living systems which in turn heat the exposed biological system causing thermal damage from within (Habash, 2002). Electric fields found in the home typically range between 0 to 10 V/m and magnetic fields can vary significantly (EMF Rapid, 2002). Most studies and reviews focus is on magnetic field exposure (IARC, 2002; WHO 2007), however, some argue that electric fields should be part of both epidemiologic and laboratory work (Coghill, 2005). One study found an association between childhood leukemia and residential proximity to power lines at distances that extend well beyond the expected influence of magnetic fields from transmission lines (Draper et al., 2005). Therefore, reducing electric and magnetic field exposure is necessary within the indoor environment. The Bau-Biologie is an organization that educates and certifies individuals on EMF has suggested that electric fields over 5 V/m and magnetic fields over 2 mG is of a concern for health for children and adults (Refer to Appendix D of this report for exposure limits prepared by Bau-Biologie).

Thousands of studies have suggested that elevated levels of magnetic fields are associated with some diseases such as child leukemia, miscarriages and infertility, multiple sclerosis, Lou Gehrig's disease, and more (Havas, 2007). Elevated levels of magnetic fields can also cause disturbances in sensitive electrical equipment and induce currents in conductors with accompanying heat (Riley, 2005). The International Agency for Research on Cancer (IARC), an agency of World Health Organization (WHO) concluded that a doubling of childhood leukemia is associated with an average AC power frequency magnetic field level of 4 mG and classified as a "(2-b) possible carcinogen", and classified electric fields as a "(3) inadequate evidence". Coincidently, magnetic fields of 4 mG or higher can cause computer screens to jitter (Riley, 2005).

Voluntary standards and guidelines have set minimum exposure levels for both the general public and occupational workers (ICNIRP, 1998; 2009). In Canada, there are no exposure limits for the general public to electric or magnetic fields, therefore, Health Canada refers to the ICNIRP exposure limits which has been argued by scientists as being too high, out of date, and not consistent with current scientific studies (Havas, 2007). However, in 2008, the Greater Toronto Authority (GTA) adopted the policy of prudent avoidance to reduce childhood exposure to EMF in and adjacent to hydro corridors only (City of Toronto Report, 2008). Therefore, the objective of this research is to design an indoor environment that does not exceed 2 mG in magnetic field levels and 5 V/m in electric fields (based on Bau-Biologie exposure limits).

2.2.2.1 Net Currents

When the currents in a pair of conductors (live and neutral) are not balanced, the circuit will result in a "net current". Net currents are produced when the neutral conductor is earthed or grounded in more than one place (Habash, 2002). Net currents can also be caused by an accidental shorting of the neutral conductor by a carpenter getting a metal screw too close (Riley, 2005). It can also occur if neutral conductors are inadequate due to increased use of electronic devices and poor quality power (Havas, 2007. The neutral is intended to return current flow back to the transformer supplying the site in order to complete its circuit, not actually to "get to ground". Figure 2.11 shows how net currents flow through the plumbing system of one house and into the next.

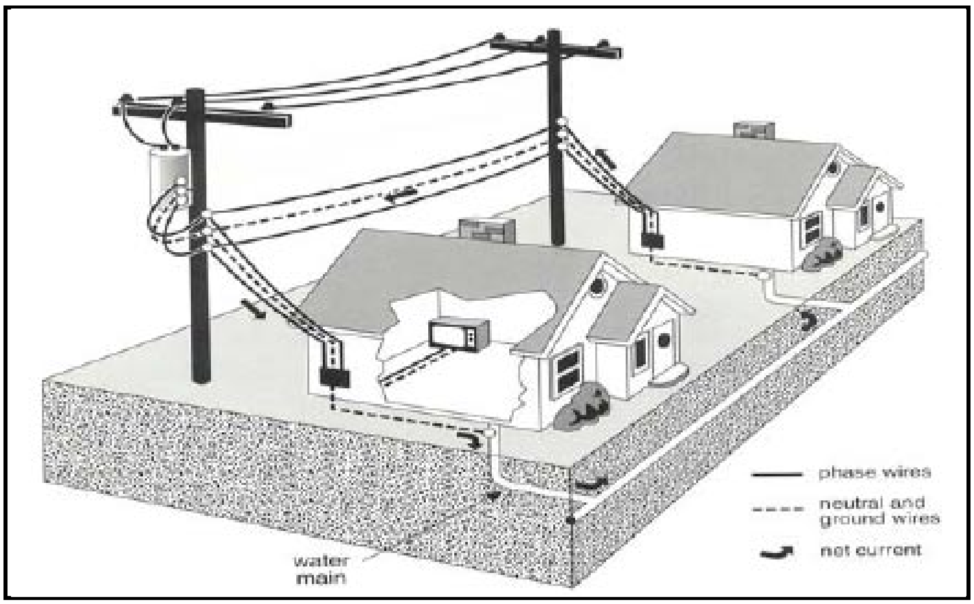

Figure 2.11: Net currents flowing through the plumbing system of one house and into the neighbouring house (Edison, 2004).

For example, in a typical two-conductor circuit, if the live conductor is carrying 10 amps and the grounding conductor is carrying 4 amps, there will be a 6 amp net current which would act like a 6 amp current in a single conductor. Thus, the magnetic field will be 12 mG at 1 meter, 6 mG at 2 meters, 3 mG at 4 meters, etc. (Riley, 2005). Ground fault circuit interrupters (GFCI's) are typically used to trip from a net current of 5 milliamps. Eliminating the magnetic field due net current requires locating the source causing the unbalance of currents.

Measuring net currents can assist in identifying the cause of elevated magnetic fields. For example, if a measurement is taken 2 feet from the suspected source, then at a distance of 4 feet from the source; if the second reading is half the first then the measurement is from a line source. If the second reading is about one fourth of the first then the measurement is from a balanced current field from a line source and the field weakens with the square of the distance, $1/r^2$. If the second measurement is about one eight the first then the measurement is a field from a coil-type source (motor or transformer) and the field weakens with the cube of the distance, $1/r^3$. [Riley, 2005]

2.2.3 Ground Current (GC) or Contact Current (CC)

Dr. Magda Havas has conducted numerous studies on ground current (GC) and contact current (CC) and has defined the issue as follows:

> *"While most of the electricity flows along wires, some of it flows through the ground and is called "ground current", previously called "stray voltage". Ground current travels along the path of least resistance and it preferentially flows through highly conductive objects including wet soils and metal pipes. Ground current is a serious problem in farming communities and has been associated with reduced milk yield for dairy cattle, miscarriages, mastitis, foot sores that do not respond to conventional antibiotic treatment, behavioral abnormalities, and premature death resulting in serious financial problems for dairy farmers. These problems often result in legal action with out-of-court settlements. Ground current is also a serious concern in urban centres as it can enter homes through the plumbing system."*

It can originate from high voltage transmission lines when the neutral conducting wire is grounded to the earth instead of the neutral current returning back to the generation plant where it is to be grounded to earth. These multiple grounding points throughout the system create ground or neutral-to-earth voltages that are at levels that are above the perception threshold for animals and people (Hofmann, 1995). Typical locations that are affected include dairy farms, feeder and confinement operations, swimming pools, water systems and residences (Hofmann, 1995).

Another study found that small electrical ground currents has been known to effect behavior, health, and milk production of cows and has sparked law suites by farmers on the utility companies in the US after high-frequency harmonics and transients above 60 Hz (poor quality power or dirty electricity) were found on metal milking stalls and in some cases cows were electrocuted when in contact with metal milking stalls (Hillman, et al., 2002).

According to the National Electrical Safety Code Handbook (1997):

> *"When the earth returns were used in some rural areas prior to the 1960's, they became notorious offenders in dairy areas because circulating currents often cause both step and touch potentials. In some cases, they have adversely affected milking operations by shocking the cattle when they re connected o the milking machines, and have affected feeding."*

According to recent studies, this problem has resurfaced today as a result of deteriorating utility infrastructure, increased use of electronic devices that affect power quality, and inadequate neutrals are increasing ground current in both rural and urban areas (Havas, 2007).

One study found that elevated magnetic field production from secondary distribution wiring arose mainly from a "net" or "unbalanced" current which occurs when some fraction of the neutral return current from a house goes back to the transformer by way of the city plumbing system and the drop wires of the neighbouring houses instead of the neutral conductor (Wertheimer and Leeper, 1982). The same study found that homes with child cancer patients also had high levels of plumbing current. This phenomenon has been labeled "plumbing current" and can be distributed throughout the house via the plumbing system.

Ground current flows through the water pipes and enter the home through the plumbing system throughout the building. In older Canadian homes, the electrical wiring is grounded through the plumbing system to the earth which results in ground current to enter through the plumbing system.
Where the ground current gets on these systems, they cause huge imbalances created elevated levels of magnetic fields from the plumbing system. In the case of multiple earthings, the net current or ground current can also get onto the gas lines, metal electrical conduit, waste pipes, oil lines telephone grounding wires, cablevision jackets, stucco wire, rain gutters and downspouts; all of which contribute to the background magnetic field in homes (Habash, 2002). Ground currents flowing through plumbing can be interrupted with isolating coupling or a dielectric coupling in the water supply pipe which could greatly reduce the exterior sources (Habash, 2002; Riley, 2005).

2.2.4 Radio Frequency Radiation

Radio frequencies (RF) are non-ionizing, higher frequency electromagnetic radiation (EMR) in the range of 3 kHz to 300 GHz (IEEE, 1995). RF have higher frequencies, higher energy, with a shorter wavelength, and falls in the radio frequency range (middle) of the electromagnetic spectrum (Figure 2.1 and 2.5). At higher frequencies, electric and magnetic fields combine to form electromagnetic fields or non-ionizing electromagnetic radiation travelling through air space from a transmitter. RF EMR can be reflected from, refracted around, or absorbed by their receivers or any object in their path including people (Habash, 2002). They are typically generated from AM/FM radio, FM TV, transmitters, radar systems, satellite systems, mobile radio, paging systems, wireless communication, DECT phones, Wi-Fi (wireless internet) broadcast and cell phone antennas, and more.

At ELF electric frequencies, both electric current and electric fields are induced inside living systems by external ELF magnetic fields (Habash, 2002). At very high-frequencies (above 100 kHz), induced electric currents heat the exposed biological system, causing thermal damage from within (Habash, 2002). Scientists have discovered that these invisible waves are travelling through our environment and interfering with power-frequency causing a host of technical and health problems including “radio wave sickness” (Firstenburg, 2001).

Historically, the term radio wave sickness was called “neurasthenic” by an American doctor, George Beard in 1868, to describe a new type of illness that appeared following the construction of railroads and telegraph systems (Firstenburg, 2001). It was later called radio wave sickness by Russian doctors to describe an occupational illness by large numbers of workers to microwave or radio frequency radiation (Firstenburg, 2001). Original symptoms included anxiety which was regarded as psychological. Radio wave sickness is caused by electricity in general, under the term “electrical sensitivity” or “electrohypersensitivity” (Firstenburg, 2001). Studies conducted between 1960 and 1998 have discovered numerous symptoms including the following:

- Insomnia, headaches, dizziness, nausea, memory loss, difficulty concentrating, irritability, respiratory illness (bronchitis, sinusitis, pneumonia), flu-like symptoms, asthma, fatigue, weakness, pressure or pain in the chest, increase in blood pressure, altered pulse rate (unusually slow), pressure behind the eyes, other eye problems, swollen throat, dry lips or mouth, dehydration, sweating, fever, shortness of breath, muscle spasms, tremors, pain in the legs or the soles of the feet, testicular or pelvic pain, joint pain, pains that move around the body, nosebleeds, internal bleeding, hair loss, digestive problems, skin rash, ringing in the ears (tinnitus), impaired sense of smell, pain in the teeth (especially with metallic fillings (Firstenburg, 2001).

Ongoing research being conducted by Dr. Magda Havas at Trent University has also discovered more symptoms including the following:

- Depression, anxiety, irritability, frustration, temper, poor sleep, chronic fatigue, and fibromyalgia (Havas, 2007).

Electrohypersensitivity (EHS) has been recognized by the World Health Organization (WHO) and is defined as (Mild, 2004):

"…a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic, or electromagnetic fields (EMFs)…Whatever is cause, EHS is a real and sometimes a debilitating problem for the affected persons, while the level of EMF in their neighborhood is no greater than is encountered in normal living environments. Their exposures are generally several orders of magnitude under the limits in internationally accepted standards."

In Sweden, EHS is classified as a disability for sensitive individuals to low frequency EMF and radio frequency radiation affecting approximately 2% of the population with sever symptoms and another 35% with moderate symptoms; in Ireland as well, the Irish Doctors Environmental Association (IDEA) is recognizing radio frequency radiation as an illness; in Canada, the Canadian Human Rights Commission report that EMF and EMR exposure (radio wave sickness associated with radar workers and EMF sensitivities associated with ground current, low frequency EMF, telecommunications, and radio frequencies on power lines) are environmental sensitivities; in San Francisco 2% suffer from severe radio frequency radiation and 35% who have moderate symptoms (Havas, 2007).

Currently in Canada, radio frequencies are auctioned off by the federal government. The last auction was held in 2008 in which the government earned approximately $4 billion in revenue from companies like Rogers Communications Inc. and BCE Inc. (Sympatico, 2010). The demand for spectrum below 1.7 GHz for wireless services, particularly in major urban areas, continues to grow unabated and Industry Canada has been approached by several parties to access spectrum for a wide range of new radio applications such as public safety, commercial and utility operation, new consumer radios, new medical and utility telemetry such as wireless monitoring in hospitals and health care facilities, automatic meter reading (AMR), and utility line load management (Industry Canada, 2010). The government is planning another auction in 2011 as more of the high frequency spectrum is needed for Canadian broadcasters who are switching to digital TV.

The studies appear to show that a growing population is becoming sensitive to electromagnetic energy from radio frequency radiation, particularly those living near broadcast or cell phone antennas (Havas, 2007). Most guidelines are based on short-term (30-minute) thermal effects and are inadequate to protect the population from long-term, non-thermal exposure (Havas, 2007). Not only is living near antennas potentially harmful, but metal objects such as wiring in the home, fences, poles, roofs, filing cabinets, metal implants or metal objects near the body (zippers, glasses, jewelry, etc) can redirect EMR and create hot spots or interfere with reception (Havas, 2007).

With current scientific data, it appears that the prudent avoidance policy should be taken more seriously with regards to building occupant exposure to radio frequency radiation. The objective of this research is to reduce the level of radio frequency radiation in a typical single-family dwelling in the GTA as a precaution.

2.2.5 Dirty Electricity

Transient electromagnetic fields (dirty electricity), in the kilohertz range on electrical wiring (4 kHz to 100 kHz), is poor quality power which occurs when electromagnetic energy (low end of the radio frequency band) flows along a conductor that deviates from a pure 60 Hz sine wave, which has both harmonic and non-harmonic (transient) components (Havas, 2000). Harmonic distortion is generated by non-linear loads such as computers, plasma televisions, energy efficient appliances, energy efficient lighting (i.e. compact fluorescent bulbs), transformer based dimmer switches, as well as arching on electrical conductors caused by loose wires (Havas, 2000). It emerged as a problem in the 1970's with the increasing use of electronics producing non-linear loads (Havas, 2006). Many electronic devices today are designed to filter out the harmonic distortion to prevent electronic failure (Havas, 2007). Figure 2.12 on the following page lists the devices that are known to cause dirty electricity.

Harmonic distortion is also generated by high frequency transients produced by radio frequency technology such as cell phone antennas and broadcast antennas by riding along transmission line conductors (Havas, 2006). With the rapid increase in radio frequency technology and erection of mobile towers, dirty electricity is also entering buildings via electrical wires (Havas, 2006).

One study found that high frequency voltage transients was the cause of an unusually high cancer incident among teachers at La Quinta, California middle school, and concluded that this type of pollution to be a carcinogen similar to ionizing radiation (Milham and Morgan, 2008). Another study found that exposure to dirty electricity and other forms of EMF pollution may account for elevated blood sugar levels among diabetics and pre-diabetics (Havas, 2008). It has also been found that people with multiple sclerosis had reduced symptoms when dirty electricity was reduced in their environment and those with progressive MS were able to walk unassisted within a few days to weeks (Havas and Stetzer, 2004, Havas, 2006).

Another study found that harmonics and transients caused an increase in the rate of electricity consumption in a residential house located in very close proximity of a mobile tower, even when all electrical devices were turned off (Havas, 2010).

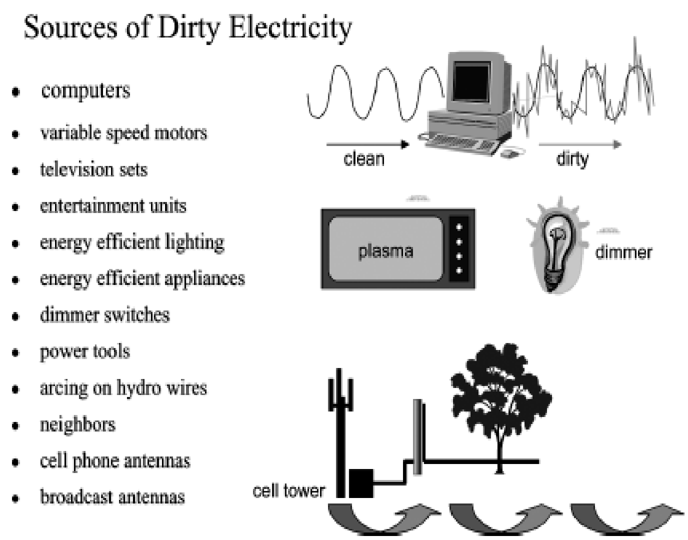

Figure 2.12: Dirty Electricity Sources (Source: Havas, 2000).

Excessive harmonics in AC power systems can cause serious problems such as overheating transformers and high currents in neutral conductors which are both potential fire hazard; it also creates electromagnetic "noise" in the form of radio emissions that can interfere with electronic equipment (Shah, 2005).

In more recent years, dirty electricity has been identified as causing symptoms resembling 'sick-building syndrome' and has also been linked to illnesses such as diabetes, multiple sclerosis, electrical hypersensitivity (Havas, 2006); it even effects milk production of cows (Stetzer and Graham, 2002). Numerous studies found that the installation of Graham/Stetzer (GS) filters in homes and schools improve occupant health and well-being (Havas and Stetzer, 2004). Symptoms in schools associated with ADD and ADHD were reduced among elementary students and improved student behavior and improved teacher performance and health (this study was repeated 3 times with the same results) (Havas, et al. 2004). The GS filter is a compact unit that plugs into an electrical outlet and it has been recommended that the installation of approximately 20 GS filters would be necessary to remove the dirty electricity from an average size residential house.

2.3 International Guidelines and Scientific Review Agencies

There are a number of international governmental and non-governmental organizations worldwide that have issued guidelines on short-term exposure limits for low frequency EMF. There is no internationally agreed upon guidelines that consider long-term exposure to magnetic fields with the low frequency range. There are several independent scientific panels that review EMF research periodically of the most current scientific research which are analyzed and published every few years. Unfortunately, not all voluntary guidelines reflect the current scientific studies.

2.3.1 International Guidelines on Low Frequency EMF

The following are organizations that have developed voluntary occupational and general public exposure guidelines for low frequency EMF exposure:

1. **The International Commission on Non-Ionizing Radiation Protection (ICNIRP)**: a volunteer standard that is most commonly cited and referenced with their last publication in 1998. This organization is in collaboration with the World Health Organization (WHO). WHO states that:

   "*…the ICNIRP guidelines for EMF exposure…are intended to prevent health effects related to short-term acute exposure. This is because ICNIRP considers the scientific information on potential carcinogenicity of ELF fields insufficient for establishing quantitative limits on exposure*".

   The ICNIRP guideline for exposure of the general public to low frequency magnetic fields is 830 mG for any 24-hr period. It is based on short term exposure only and does not include public exposure to long term acute exposure which is the case for distribution of electricity. It is based on electrical stimulation outside the body resulting in electrical signals within the body that are within normal physiological intensities that might affect neural impulses and does not consider cancer as a possible outcome.

   In Canada, EMF exposure guidelines come under the jurisdiction of Health Canada. Currently, there are no Canadian standards for occupational and general public magnetic field exposure at frequencies in the ELF EMF spectrum range (0 Hz to 3 kHz). Health Canada will reference the ICNIRP guidelines for 830 mG for a 24-hr period (Havas, 2007).

   According to an expert testimony by Professor Magda Havas in 2007, the scientific literature for magnetic field exposure and the ICNIRP/Health Canada guidelines show a serious discrepancy in the exposure limits. The associations based on epidemiological studies and cause-effect relationships based on laboratory experiments suggest that magnetic fields within the range of 2 to 16 mG are harmful, but, Canadian guidelines allow exposure of the general public to magnetic fields up to 830 mG for any 24-hour period which is clearly outdated and should be reviewed based on the scientific studies.

Table 2.2: Magnetic Fields Associated with Health Effects

RESPONSE	EXPOSURE	mG
Childhood leukemia	Residential	2-4
Adult leukemia	Occupational	3-10
Adult brain tumors	Occupational	3-10
Breast Cancer	Epidemiology, in vivo and in vitro studies	3-12
Miscarriage	First Trimester	16
ICNIRP and Health Canada Guidelines	General Public	833

Table 2.2: Levels of magnetic fields that have been associated with adverse health effects and existing international and federal guidelines recommended by Health Canada (Source: Havas, 2007).

The expert testimony by Professor Havas proceeds to include the following international guidelines: Italy guidelines of 2 mG for schools has been proposed; Sweden guidelines between 2-3 mG have been recommended for locations where children live and play; Switzerland is considering 10 mG; and in Israel it is difficult to sell a home if values exceed 10 mG (Havas,2007).

2. **ANSI/IEEE C95.6 Standard:** EMF exposures for the general public and workplaces.
3. **American Conference of Governmental Industrial Hygienists (ACGIH):** an American organization providing guidance for occupational exposure.
4. **UK National Radiological Protection Board (NRPB):** has recommended the adoption of the ICNIRP guidelines – NRPB, 2004a and 2004b.
5. **Bau-Biologie:** provides exposure limits in sleeping rooms for children and adults.

Table 2.3: International ELF EMF Exposure Limits

	Electric Field Strength (kV/m)		Magnetic Flux Density (mG)	
ELF EMF Guidelines (60Hz)	**Public**	**Occupational**	**Public 0.1uT=1mG**	**Occupational**
ICNIRP (1998)	4.17 kV/m	8.33 kV/m	833 mG	4200 mG
IEEE (2002)	5 10^{x}	20	9000 mG	27,100 mG
UK NRPB	10kV/m	10kV/m	13,300 mG	13,300 mG
BAU-BIOLOGIE (for sleep areas)	≤1 V/m children ≤1 V/m adults		≤ 1 mG children ≤ 1 mG adults	
Power Lines				
Hydro-Quebec Edge of Right-of-Way	2 kV/m at 1m above ground			
Hydro-Ontario Edge of Right-of-Way	3 kV/m at 1m above ground			
Hydro-BC Edge of Right-of-Way	5 kV/m at 1m above ground			
New York Edge of ROW(ROW500kV)	1.6 kV/m (11.8kV/mROW)		200mG (>230kV)	200mG (>230kV)
Florida Edge of ROW			150mG (2-230kV) 200mG (500kV) 250mG(500kVROW)	150mG (2-230kV) 200mG (500kV) 250mG(500kVROW)

2.3.2 International Guidelines on Radio Frequency Radiation

There are a few organizations that have developed voluntary occupational and general public exposure guidelines for radio frequency radiation exposure. The radio frequency guidelines vary by order of magnitude in countries around the world (Figure 2.13). According to an expert testimony by Professor Havas at Trent University, the discrepancy is due to the fact that some countries place a greater value on science and on preventative health regulations while others may place a greater value on commerce. Volunteer organizations setting safety standards such as ICNIRP or ANSI/IEEE argue that “safe” radio frequency exposure tests rests on the fact that exposure is too weak to produce a rise in body temperature or a “thermal” effect. However, Professor Havas argues that whether non-thermal effects occur is not the issue, the issue is at what level doe these non-thermal effects occur and what are the safe levels of long-term exposure. According to Figure 2.13, non-thermal effects occur far below most of the international guidelines.

In Canada, the federal government has developed Safety Code 6 which is radio wave frequency exposure limits for the general public and workers and defines the exposure limit as 5 W/m^2. However, the data from Figure 2.13 clearly indicates that non-thermal effects occur far below the guidelines.

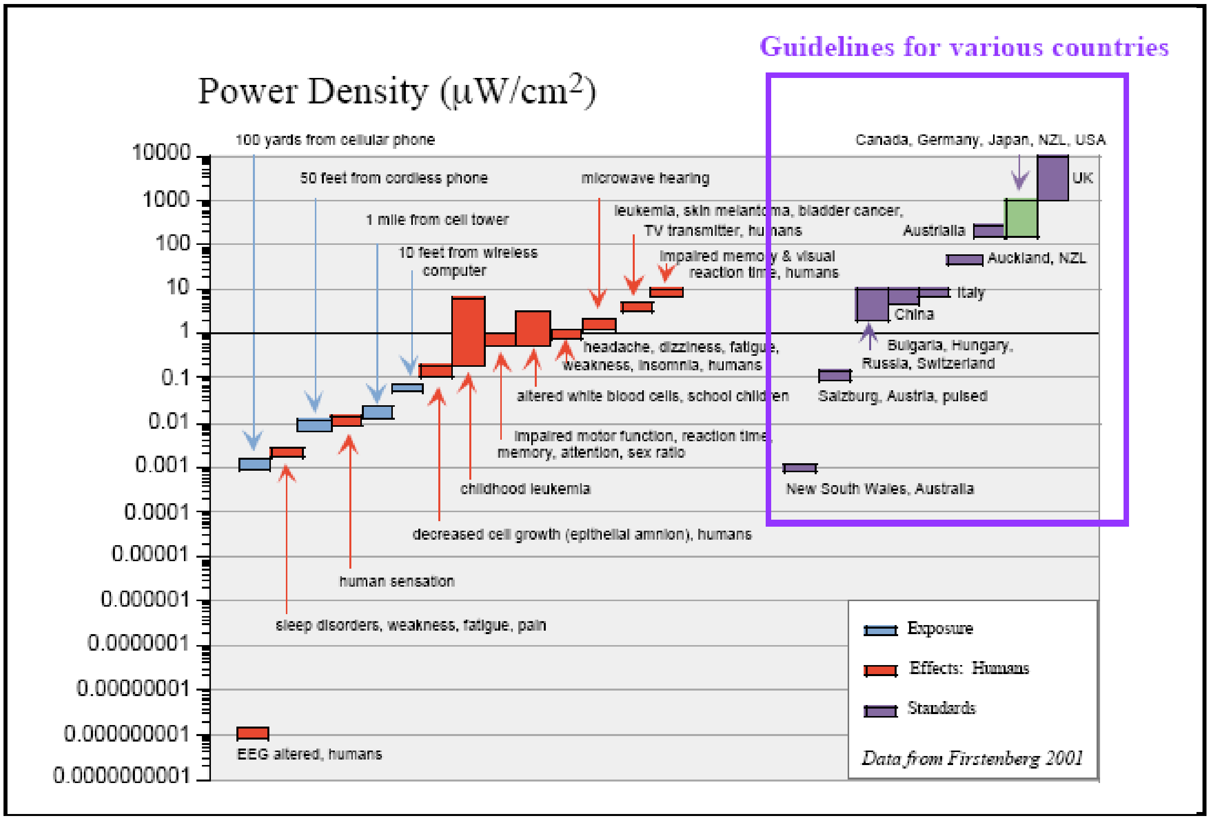

Figure 2.13: Guidelines, exposures and effects of radio frequency radiation at various power densities. Data from Firstenberg, 2001 (Source: Havas, 2007).

2.3.3 National and International Reviews

In the absence of scientific certainty regarding the health effects from radio frequency radiation and electromagnetic fields, many organizations conduct periodical reviews of the scientific literature in order to evaluate exposure limits. Some of these organizations include:

1. The Federal-Provincial-Territorial Radiation Protection Committee (FPTRPC): a Canadian review committee with a mission to harmonize the practices and standards for radiation protection within the Federal, Provincial, and Territorial jurisdictions. Their latest publication was January 2005. The FPTRPC is made up of the following government organizations (making up the ELF Working Group):
    - Canadian Nuclear Safety Commission
    - Health Canada – Radiation Protection Bureau

- Provincial and Territorial Radiation Protection Programs

Currently Health Canada does not considered ELF EMF as a health threat and references the ICNIRP guidelines for exposure limits.

2. The World Health Organization (WHO): an international organization monitoring cancer initiated the International EMF Project prepared a document (based on a 10 year review of research). WHO has developed a framework document entitled "Guiding public health policy options in areas of scientific uncertainty" (June, 2005).
3. The National Institute of Environmental Health Sciences (NIEHS): an American review organization for EMF exposures in homes and workplaces with last publication in 2002 (based on a 7 year review of research).

   NIEHS (1998) states that this classifying of ELF EMF as a "possible carcinogen" (Group 2B) is:

   "a conservative, public-health decision based on limited evidence of an increased risk for childhood leukemia's with residential exposure and on increased occurrence of CLL (chronic lymphocytic leukemia) associated with occupational exposure. For these particular cancers, the results of vivo, in vitro, and mechanistic studies do not confirm or refute the findings of the epidemiological studies."

4. The National Radiological Protection Board (NRPB): A UK review organization.
5. The International Agency for Research on Cancer (IARC): is associated with WHO.
6. The International Commission for Non-Ionizing Radiation Protection (ICNIRP): published guidelines in 1998 for low frequency magnetic fields and currently has a 2009 revision in draft.

2.3.4 Regulation and the Precautionary Principal (PP)

Current scientific studies have confirmed adverse biological and health effects from exposure to EMF and EMR; however, the Canadian regulatory process is slow and will take years before acceptable guidelines are established to protect human and also animal health. Therefore, in the absence of regulatory guidelines, the Precautionary Principal (also referred to as the Prudent Avoidance Policy) can be applied. The following has been said regarding the Precautionary Principal (Havas 2007):

The Precautionary Principal is Principal 15 of 192 Rio Declaration on Environment and Development and it states the following:

> *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capability. Where there are threats of serious or irreversible damage, lack of full*

scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

The International EMF Project initiated by WHO developed a framework document entitled "*Guiding public health policy options in areas of scientific uncertainty*" (June 2005). The guiding principles apply to electromagnetic fields and include the following fundamental points:

1. While science is the basis for establishing risk, appropriate actions are also based on technical, economic, and political realties.
2. Protecting the vulnerable in our society is an important consideration and relates to the research on childhood leukemia's and miscarriages.
3. Special attention needs to be paid to ubiquitous exposures which may have a significant public health risk.
4. Critical health issues need to be considered and put into context.
5. The inability to find an adverse health effect does not necessarily mean that an adverse health effect does not exist.
6. The two extremes of action are banning an agent (or activity) or taking no action at all, both having their adverse consequences.
7. Childhood leukemia warrants full cost-effective analysis of precautionary measures.

Health Canada prepared two documents entitled "*A framework for the Application of Precaution in Science-based Decision Making about Risk*" published in 2003, and "*It's Your Health Fact Sheet on EMF's*" published in 2004. From the first document, the City of Toronto has adopted the 'Prudent Avoidance Policy' for children and exposure to high voltage transmission lines only. Clearly, there is a need for the *precautionary principal* or *prudent avoidance policy* to be extended to homes, schools, and the work place. It is intended that this research shows how the Prudent Avoidance Policy can be applied in new or restoration construction projects of residential houses.

2.4 Shielding EMF Pollutants

Shielding the various forms of EMF pollutants from the indoor environment requires using different methods and materials for an existing building to safe levels should be low-cost or no-cost according ot the precautionary principal. This is not always possible where a certain type of EMF or EMR is elevated and requires mitigation or shielding. However, for new construction and renovations, careful selection of the mechanical, electrical, and lighting systems from the start of the project can be most cost effective in shielding.

2.4.1 Low frequency Electric Fields

Electric fields unlike magnetic fields are such that they are affected by conducting objects, including the ground, most building materials, trees, humans and animals creating local areas of high electric fields (Kheifets et al., 2010). Transmission lines produce greater electric fields than smaller distribution lines because their voltages are higher, conductors are larger, and phase spacing is greater. At ground level the electric fields from overhead lines are around 10 kV/m, and underground cables produce insignificant electric field levels outside their perimeter due to various shielding screens (EMF Rapid, 2002). Electric fields entering a home from an outside source are typically 10 to 1000 times lower than fields outside (NRPB, 2001). The most common source of electric fields within a home is from electrical wiring and appliances (operating or just plugged in) typically in the range of 1 and 10 V/m (Kheifets et al., 2010). Thus, shielding from indoor electrical wiring and appliances is more crucial than from outside sources.

Since electricity travels along the least path of resistance, shielding the electrical wiring conductors within a conducting material such as commercial grade flexible steel BX cable will mitigate the electrical fields within the home. BX cable is also known as armored cable and was typically used in older residential construction, then later replaced with the modern day “Romex” non-metallic sheathed electrical cable (Figure 2.14).

Figure 2.14: Example of flexible steel BX armored cable (left) and brand name Romex residential wiring (right).

However, using BX cable will not eliminate electric field exposure from the receptacles, light switches and fixtures. For additional shielding at these locations, the installation of a demand switch per dedicated zone or room will shut off electrical power at the main electrical panel by using a remote control device (Figure 2.15). These devices are typically used for bedrooms during sleep hours when occupants would otherwise be exposure for a longer period of time.

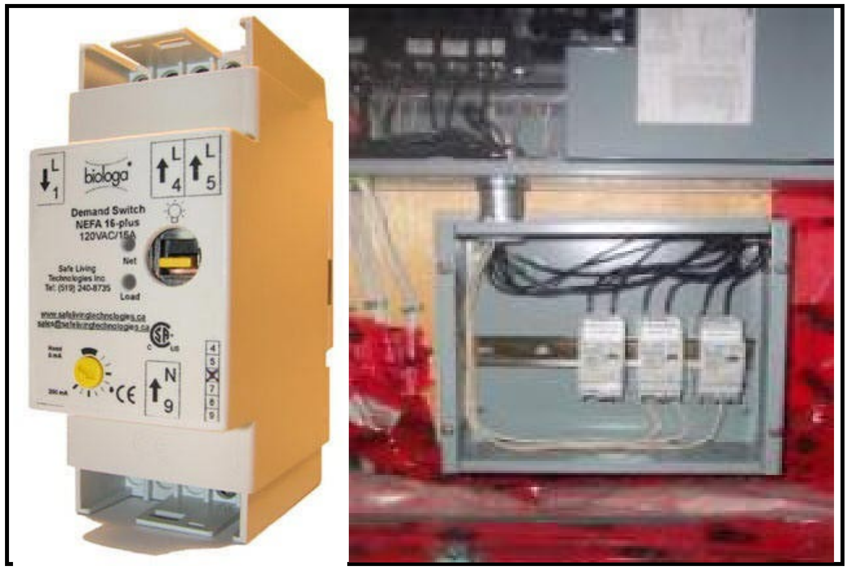

Figure 2.15: Demand switch (left) and installation of demand switches next to the electrical panel (right).

(Source: Safe Living Solutions)

Electric fields from appliances can result in high exposure levels in the order of a few hundred V/m near some appliances, but diminish to lower levels after about a meter (Kheifets et al., 2010). One solution to reduce exposure is to select appliances that operate with gas instead of electricity which not only reduces electric field exposure, but also reduces electricity consumption. Also, appliances can be turned off and produce no magnetic fields, however, as long as it is plugged in, it will produce an electrical field. Therefore, unplugging electronics and appliances when not in use would mitigate unnecessary electric field exposure, particularly in the bedroom during sleep hours where occupants would otherwise be exposed for longer periods of time.

2.4.2 Low frequency Magnetic Fields

Magnetic fields surround any electrical device resulting from the flow of current through the wires and device, and increases in strength as the current increases. Shielding magnetic fields is not as easy as with electric fields. Magnetic fields penetrate through almost all objects including buildings, people, and animals (Habash, 2002). Although the magnetic field strength drops rapidly within 4 feet from the source (EMF Rapid, 2002), Mu-metal and electrical steels such as silicone steel are used to shield strong magnetic fields due to their high permeability (Kim et al, 2010). Shielding magnetic fields using either Mu-metal or electrical steels are only effective below 100 kHz, above which requires high frequency shielding (Kim et al., 2010). Mu-metal is a nickel-iron alloy (approximately 75% nickel, 15% iron, plus copper and molybdenum) that has very high magnetic permeability. When magnetic lines of flux encounter high permeability material, the magnetic forces are both absorbed by the material and redirected away from the target; the most effective shields are constructed as enclosures such as boxes or cylinders with end caps (MuShield, 2010).

Within a home, high levels of magnetic fields will emit from the electrical panel, however, the magnetic field strength will drop rapidly within 4 feet from the panel. As long as occupants are more than 4 feet from the panel, shielding would not be required. Other sources of high magnetic fields within a home are typically from faulty wring and grounding (Riley, 200), therefore, correction of any errors would mitigate the magnetic fields. Finally, electronics and appliances will generate magnetic fields when they are turned on, therefore, keeping a distance away from the source will help reduce magnetic field exposure (EMF Rapid, 2002). Figure 2.16 shows how a printing machine reduces in magnetic field strength from 90 mG at 6 inches from the printer to 1 mG at 4 feet away.

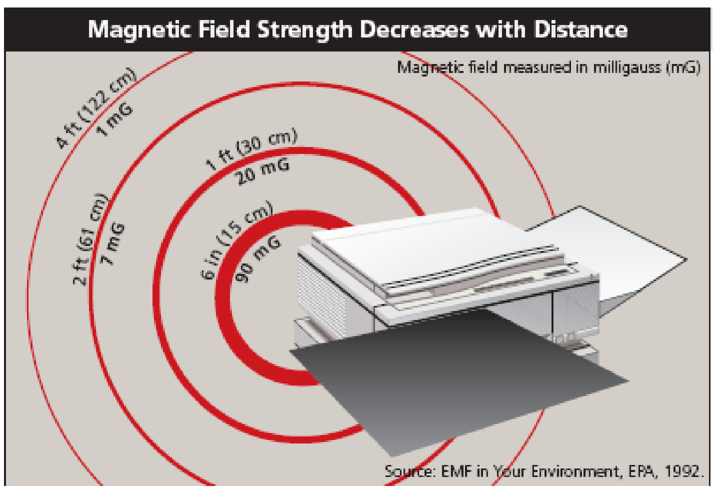

Figure 2.16: Example of how distance from the source reduces magnetic field exposure (EMF Rapid, 2002).

2.4.2.1 Shielding Magnetic Fields near Overhead Transmission or Distribution Lines:

High voltage transmission lines produce high levels of magnetic field strength, the stronger the voltage the greater the magnetic field strength. According to Figure 2.10, the magnetic field strength will drop to a very low acceptable level at about 300 feet from the high voltage transmission line. Therefore, a residential home and/or building should be approximately a minimum of 300 feet from the vicinity of transmission lines.

Studies have been conducted on reducing the magnetic fields from the transmission lines through a variety of techniques such as increasing pole (structure) height, increasing the width of right-of-way, reducing conductor (phase) spacing, rearranging the geometry, and more (Edison, 2004).

Figure 2.17 shows how magnetic field reduction can be achieved for secondary distribution wires through various configurations over pedestrian walkways.

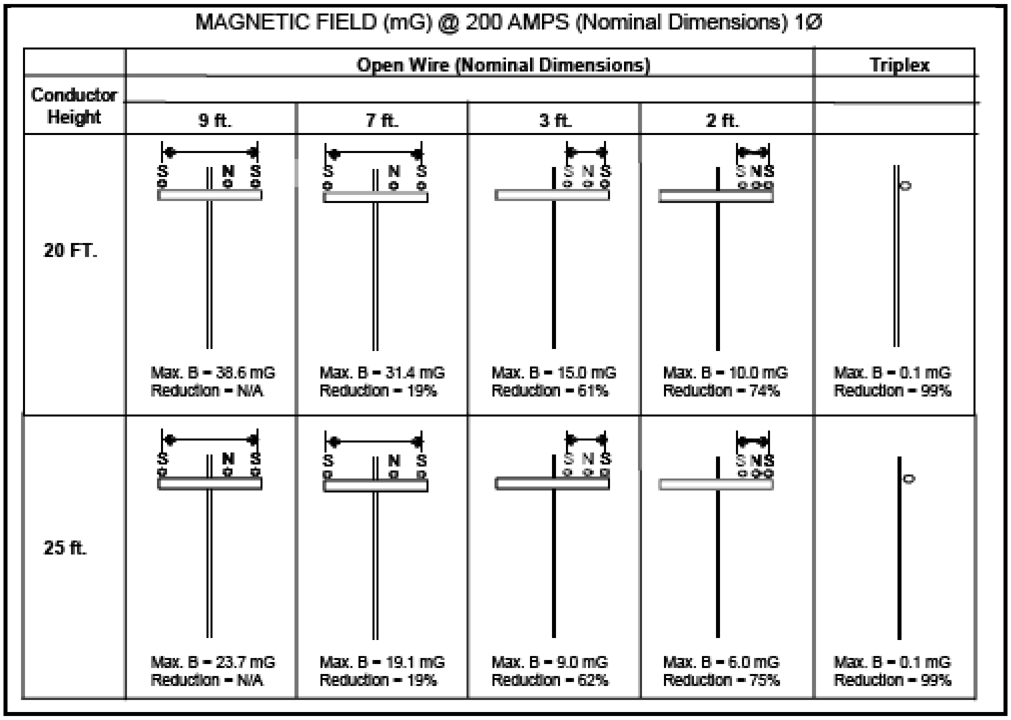

Figure 2.17: An example of magnetic field levels calculated for 20 feet and 25 feet ground clearance and various open-wire secondary configurations which show that either closer wires or taller poles can reduce magnetic field levels or pedestrian walkways (Edison, 2004).

2.4.2.2 Shielding Magnetic Fields near Power Cables:

The results of one study has found the following: for magnetic fields generated by three-phase electric currents, mu-metal is the best in shielding at a weak magnetic field, however, silicon steels are better than mu-metal at a strong magnetic field; electrical steels such as silicon steel are cheaper than mu-metal, and have a higher permeability at a strong magnetic field strength due to higher saturation induction than mu-metal; double-layer shielding with silicon steel (inner) and mu-metal (outer) results in an excellent shielding performance for even stronger magnetic fields; the results are due to change in shielding effectiveness of magnetic materials with magnetic field strength (Kim et al, 2010).

For magnetic fields generated by single-phase current, a magnetic shield can increase magnetic fields or have no practical effect on shielding performance, depending on the position of the electric source. This result can be explained by vector composition of the original field and the secondary field produced by eddy currents. (Kim et al, 2010).

A cost effective solution for shielding magnetic fields in a residential building would be to use electrical steels rather than Mu-metal. It is unknown at what point the absorbing metals become completely saturated, therefore, routine field measurements and monitoring may be required.

2.4.2.3 Open-Type Magnetic Shielding Method:

Magnetic shielding has always been arranged without any space between the magnetic shielding materials to achieve a sufficient magnetic shielding effect. However, one study found that a wall made by aligned strips with gaps (open-type magnetic shielding method) could achieve almost the same effect of magnetic shielding as in a solid shielded wall (Saito, 2008). The advantage of this type of shielding system is that light, air, and heat can pass through a wall constructed using the open-type magnetic shielding method which creates a wide range of applications. For example, in the medical field, the MRI rooms can be made to an open atmosphere. Currently, MRI rooms are shielded by walls of conventional plate-like magnetic material to reduce the leakage of magnetic flux density under 0.5 mT outside examination rooms. This type of application is more suitable for larger projects rather than smaller residential applications.

2.4.3 Radio Frequency Radiation Shielding

Radio frequencies travel through air space between a transmitter and receiver unless obstructed by large building structures which reduce radio signal strength and interfere with wireless communications due to strong attenuation caused by propagation through the building materials and scattering by the structural components (Young, 2010). Radio frequencies can be reflected from, refracted around, absorbed or transmitted by their receivers or any object in their path including people and animals (Habash, 2002). The amount of reflection, transmission, or absorption would depend on the material type, and radio frequency and wavelength. In general, obstructions containing conducting materials, such as fine metal mesh or perforated sheet metal, are very effective in attenuating radio frequency radiation by blocking the external static electrical field component of the electromagnetic radiation wave causing the electrical charges within the conducting material to redistribute them so as to cancel the field effects (Young, 2010).

Most conducting materials are metallic, but can also be non-metallic materials such as wet soils, wet concrete, conductive concrete, graphite, salt water, tap water, plasmas, and polymers. Silver is highly conductive but very expensive, so copper and aluminum are more commonly used and more cost effective. The conducting material must be grounded to dissipate any electric currents generated from the external radio frequency radiation and thus block a large amount of the electromagnetic interference. Significant attenuation of radio frequency radiation can be achieved with a “faraday cage” shield in which the effectiveness of the shield depends on the geometry of the metal mesh.

Historically, the first electromagnetic shield enclosure was constructed by physicists Michael Faraday in 1836, known as the “faraday cage” or “faraday shield”. Today, the faraday cage is constructed of conductive materials such as copper mesh and used in facilities that require no radio frequency radiation interference. Copper mesh is a good conducting material that can shield an interior room from external EMR as long as the openings in the mesh are significantly smaller than the radio frequency wavelength so that it cannot pass through (Gratton, 2008). The faraday shielding concept has been applied to different material applications such as fabrics and paints which can be just as effective as the traditional metallic mesh room enclosure.

From a health perspective, it is important to shield building occupants from EMR (Havas, 2007). As the electromagnetic spectrum becomes more crowded with more high frequencies being auctioned off (Industry Canada, 2010), those involved in the design of wireless communications systems are becoming aware that buildings constructed of various materials are interfering with wireless communications and need to determine the reflection and transmission properties of various commonly used building materials (Dalk, 2000). Numerous studies have been conducted to determine how radio waves perform when blocked by different building materials or exterior wall composition.

Buildings can be constructed from a variety of materials and systems. The exterior wall assembly is a composition of materials and includes the exterior cladding and structural framing. The components of an exterior wall assembly and structural system vary from one building type to another depending on the size, height, and location of the building. In general, all buildings require a structural frame to hold up the building, and an exterior roof and wall cladding to protect the inside from exterior environmental elements such as wind, rain, and snow.

The complexity of construction can make designing communication systems difficult. Transmission and reflection coefficients provide communication system designers an estimation of the attenuation due to transmission through obstacles and obtaining dielectric parameters of building materials (Alejos, et al., 2008). It has been found that there is a loss in transmission between approximately 12 to 13.5 dB across various radio frequencies tested through a variety of building materials (Young, et al., 2010). Glass, wood, plasterboard, and chip wood are materials that provide almost no shielding effectiveness to radio frequency radiation (Alejos, et al., 2008).

2.4.3.1 Brick, Mortar, and Concrete Structures

Attenuation results of one study tested various building materials at 40 GHz. The results indicated that various materials that present large values of attenuation in decibels per centimeter, such as mortar, brick, and concrete walls, can be used to shield base stations where shielding is required (Alejos, et al., 2008). Therefore, traditional brick and mortar and concrete are good shielding materials to radio frequency radiation.

Conductive concrete typically used for roads, ramps, bridges where de-icing is required, contains a certain amount of electrically conductive materials in the regular concrete mix such as steel fibres and carbon products (Concrete Technology Today, 2004).

2.4.3.2 Reinforced Concrete Structures

A building constructed with a reinforced concrete structure severely attenuates radio signals resulting from reflections and wall penetrations (Dalke, et al., 2000). Reinforced concrete walls are constructed with conductive materials such as wire meshes and reinforcing steel rebars of various dimensions and spacing. The maximum and minimum of the transmission and reflection coefficients depend on complicated interactions between the rebar geometry, wall thickness, and electrical properties (Dalke, et al., 2000).

At lower radio frequencies, the transmitted signal is attenuated by the rebar structure particularly when the incident electric field is parallel to the rebar, and, as the frequency increases, the effects of the wall become more pronounced and result in large than expected transmission coefficients (Dalke, et al., 2000). Also, as the frequencies increase, the transmission and reflection coefficients vary significantly. The average loss in most cases is approximately 10 dB, with rapid fluctuations on the order of 20-30 dB (Dalke, et al., 2000).

2.4.3.3 Green Roofing Systems

A green roof is a type of building envelope system that supports living vegetation to improve the performance of the building as well as provide environmental benefits. This concept has also been incorporated into exterior and/or interior walls. These systems are also referred to as “living roof” or “living wall” systems. The green roof system can be built on either a flat or sloped roof and is commonly found in European countries and has become increasingly popular in North America. The Toronto City Council adopted the Green Roof Bylaw in May 2009 which allows them to require and govern the construction of green roofs in Toronto.

There are two types of green roof systems for flat roofs: “extensive” vegetation or “intensive” vegetation. Figure 2.18 is an illustration of the two types of roof systems. An extensive green roof is a low-maintenance, self-sustaining landscaped roof system, and an intensive green roof is more labour-intensive landscaped roof consisting of shrubs, small trees, and sometimes deliberate placement of wildlife and insect species.

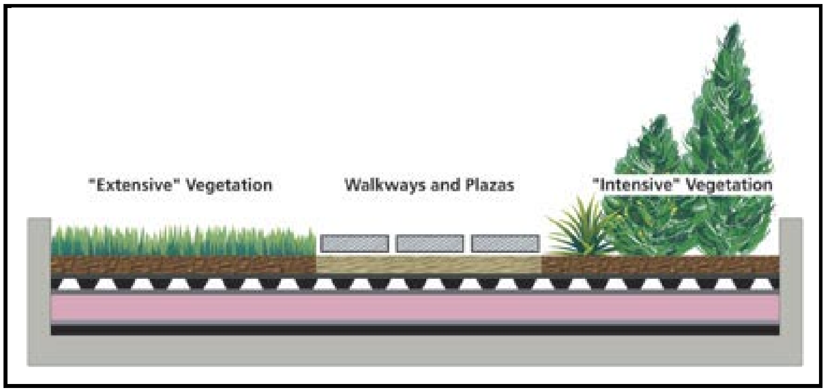

Figure 2.18: Extensive green roof system (left) and Intensive green roof (right) (Source: BAKOR).

The performance benefits of a green roof system include: a long roof lifespan, improved sound insulation, reduced heating and cooling requirements, reduced stormwater run-off, trapping of gaseous and particulate pollutants, alleviation of urban heat islands, and increased biodiversity (Doshi, 2005). A study conducted at the University of Kassel, Germany, has reported that radio frequency radiation transmission is reduced by 99.4% with a green roof of 16 cm. substrate; also, wild grasses reduce radiation in the range of 2 GHz by 24 dB which corresponds to 99% shielding; and a shielding of up to 99.999% was achieved by combining the green roof system with a 24 cm. thick mud brick dome (Minke, 2007).

Figure 2.19 illustrates the effectiveness of shielding radio frequency radiation between 0.5 GHz to 5 GHz of various building materials. It appears that vegetated roofs provide the greatest shielding effectiveness compared to other building systems such as roofs without vegetation, bricks, concrete blocks, aluminum sunshades, metal insect screens, and double-glazed windows with a gold film coating. Reflective metallic roof surfaces may also provide radio frequency shielding but has not been tested. Copper roofing and/or siding would provide excellent shielding as well.

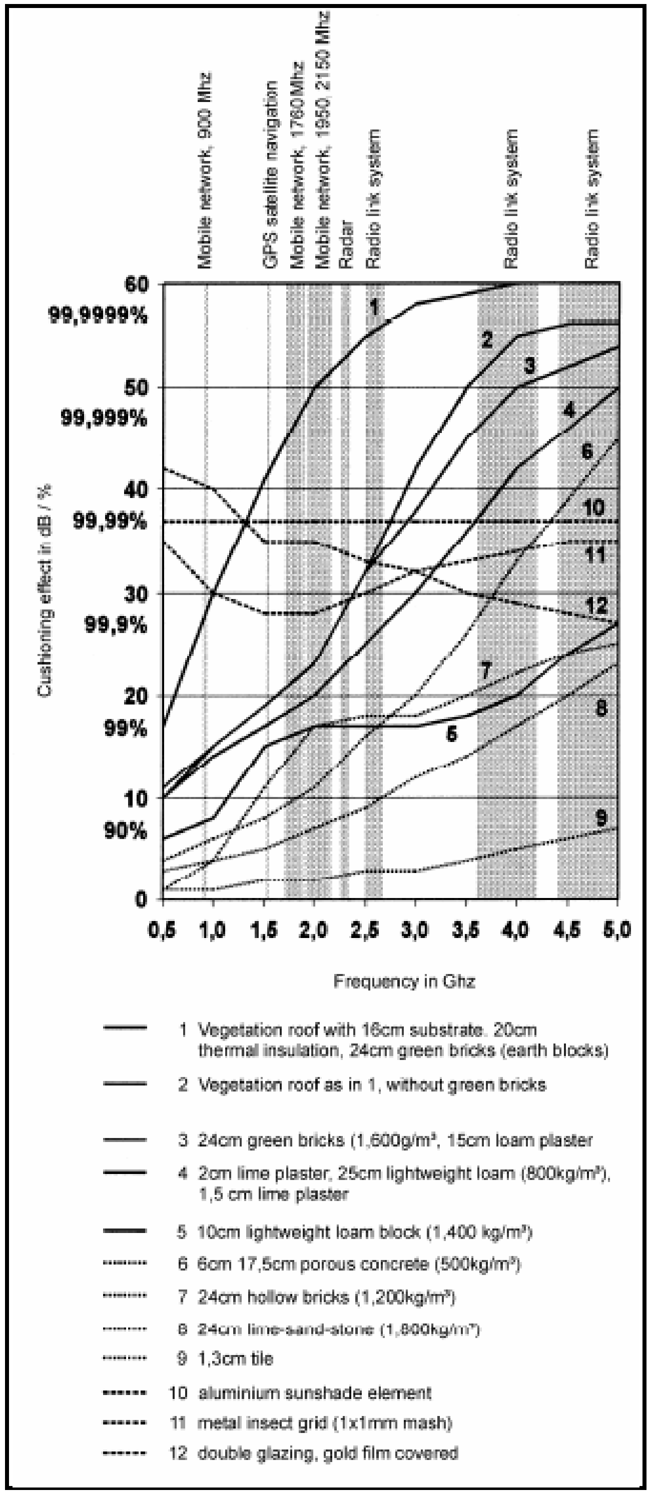

Figure 2.19: Shielding effectiveness of radio frequency radiation on different building materials (Minke, 2007).

2.4.3.4 Low-E Coating on Windows

A low-emittance (low-E) window coating is a microscopically thin, transparent metallic film that is deposited on a window pane to prevent heat flow through the window pane. Although the primary use of low-E window is for energy efficiency by keeping the heat in during winter days and keeping the heat out during summer days, the metallic coating is conductive and can provide some shielding from exterior radio frequency radiation. However, if wireless communication is used inside the building, the radio frequency radiation will be reflected back into the building and absorbed by the occupants. Therefore, the use of low-E coatings can be very beneficial for shielding purposes, but the use of wireless communication indoors should be avoided.

Figure 2.19 illustrates the shielding effectiveness of a double-glazed window with gold thin film to have a shielding effectiveness of 99% and 40 dB at 0.5 GHz, but reduces to by approximately 20 dB at 5 GHz. It appears that as the radio frequency increase, the shielding effectiveness reduces, but still provides good overall shielding performance (Minke, 2007).

2.4.3.5 Conductive Knitted Fabrics

Production of conductive knitted fabrics has increased as newer applications have emerged such as radio frequency shielding (Li, 2009). Conductive knitted fabrics are manufactured with metallic strand woven into the construction of the textile which can conduct electricity. Conductive fibers consist of a non-conductive or less conductive substrate, which is then either coated or embedded with electrically conductive elements, often carbon, nickel, copper, gold, silver, or titanium. Substrates typically include cotton, polyester, nylon, and stainless steel to high performance fibers such as *aramids* and *PBO*. Semi-conducting textiles can also be made by impregnating normal textiles with carbon or metal based powders.

2.4.3.6 Conductive Paint

Conductive water based paints are now available providing radio frequency shielding in the range of 1 GHz to 18 GHz which is a very simple and easy solution for residential applications. As with any conductive material, grounding is required to prevent electric shock (Y-Shield, 2010).

2.4.3.7 High Performance RF Reflective and Absorbing Materials

There are many new products available on the market today designed to either reflect or absorb radio frequencies. Significant radio frequency attenuation can be achieved for specific ranges. Applications include very light, thin, flexible, fire resistant, durable materials that can be applied directly to studs, standard sheetrock and other structures using simple and inexpensive methods similar to wallpapering (FlexiShield, 2010). These types of applications are very easy and cost effective in commercial and residential buildings where radio frequencies need to be shielded.

2.4.3.8 Avoidance of Wireless Technology

One of the most effective ways in reducing radio frequency radiation is by avoiding the use of wireless technology such as cell phones, baby monitors, DECT wireless phones, Wi-Fi internet, satellite dishes, and microwave ovens. Wi-Fi internet can be replaced with cable connections, the microwave ovens can be avoided, and cell phone use could be avoided or used only for emergency purposes. As the public becomes more aware of the risks of wireless communication, more EMR shielding devices are becoming available on the market such as shielding cell phone and blackberry cases.

The following was taken from an expert testimony from Dr. Magda Havas on DECT phones:

DECT is an acronym for Digitally Enhanced Cordless Technology, previously known as Digital European Cordless Technology. It is a technology that originated in Germany and has spread to other countries, including Canada. DECT phones operate at 2.4 GHz and 5.8 GHz and provide a digital signal that is both powerful and clear. It can be used up to 300 meters from their base station (cradle). Unlike other cordless phones, DECT phones continuously emit microwave radiation at full power as long as the base station is plugged into an electrical outlet whether it is being used or not. Baby monitors using DECT technology are the same.

Clearly, this technology is exposing people to unnecessary microwave radiation continuously at a dangerous level that is above a microwave oven which operates (enclosed) at 2.45 GHz. According to Powerwatch in the UK, DECT monitors expose babies to more pulsing microwave radiation than living near a mobile phone base station mast and that babies would sleep better with no crying when DECT monitors were removed from the baby room.

2.4.4. Dirty Electricity Shielding

Studies have provided evidence that high frequency voltage transients existing on electrical power wiring is an important predictor of cancer incidence in an exposed population (Milham and Morgan, 2008). This form of electrical pollution is electrostatic fields that vary rapidly in a random or noise like pattern created by radio frequency signals riding along the 60 Hz power frequency on electrical wiring and has a similar sinusoidal waveform (Graham, 2002). High frequency voltage transients found on electrical wiring both inside and outside of buildings are caused by an interruption of electrical current flow which the electrical utility companies refer to as "dirty power" (Milham and Morgan, 2008). Dirty power is also referred to as "dirty electricity" (Havas and Stetzer, 2004). Figure 2.20 is an oscilloscope waveform showing the 60 Hz (blue) sinusoidal wave (channel 1) and the high frequency (pink) microsurges (channel 2) on indoor wiring (Havas, 2004).

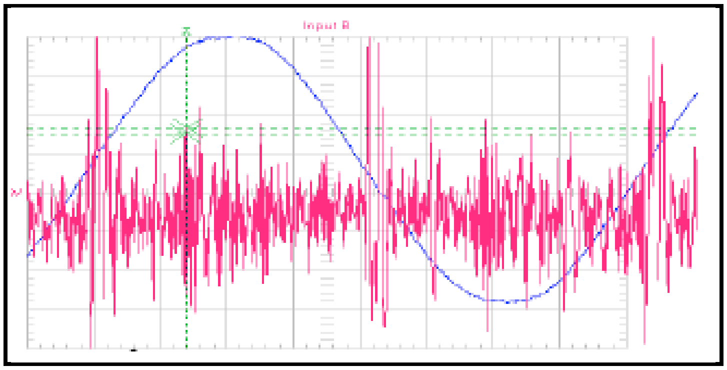

Figure 2.20: Oscilloscope waveform showing 60 Hz (blue) sinusoidal wave (channel 1) and high frequency (pink) microsurges (channel 2) on indoor wiring (Havas and Stetzer, 2004).

Figure 2.21 below shows how the installation of the G/S filter drastically reduces the high frequency voltage transients on the electrical wiring. Using a G/S meter, the readings should be below 30 GS units, and readings between 30 and 50 are marginally acceptable, while readings above 50 indicate that more filers are required (Havas and Stetzer, 2004).

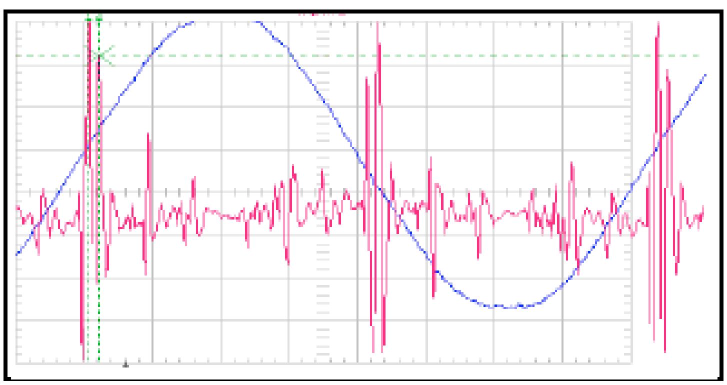

Figure 2.21: Reduction of high frequency voltage transients with a installed G/S filter (Havas and Stetzer, 2004).

The following has been reproduced to explain the GS technology (Milham and Morgan, 2008):

> *Each interruption of current flow results in a voltage spike described by the equation V=L x di/dt, where V is the voltage, L is the inductance of the electrical wiring circuit and di/dt is the rate of change of the interrupted current. The voltage spike decays in an oscillatory manner. The oscillation frequency is the resonant frequency of the electrical circuit. The G/S meter measures the average magnitude of the rate of change of voltage as a function of time (dV/dT). This*

preferentially measures the higher frequency transients. The measurements of dV/dT read by the meter are defined as GS (Graham/Stetzer) units. The bandwidth of the G/S meter is in the frequency range of these decaying oscillations.

A new metric, GS units, measured with a Graham/Stetzer meter (G/S meter) also known as a Microsurge II meter (MS II meter), measure these high frequency voltage transients by plugging in the meter into electrical outlets which displays the average rate of change of these frequency voltage transients that exist everywhere on electric power wiring (Milham and Morgan, 2008). Just as electronic equipment is protected with surge suppressors, the G/S filter (Figure 2.22) has been designed to reduce the amplitude of microsurges on indoor wiring in the range of 4 kHz to 100 kHz (Graham, 2003).

Figure 2.22: A G/S filter designed to reduce the amplitude of microsurges on indoor wiring (Havas & Stetzer, 2004).

An approximate 20 G/S filters are required in an average residential house to reduce the dirty electricity to a safe level below 50 G/S units (Havas and Stetzer, 2004). It is recommended that at least two filters be installed at the main source of electricity being the electrical panel, also at locations where one spends a significant amount of time such as the bedroom, home office, and entertainment centers (www.EMF Solutions.com). Another way to measure dirty electricity is by using an AM radio which is a sensitive detector of dirty power when tuned off a station, giving a loud buzzing noise in the presence of dirty power sources even though the AM band is beyond the bandwidth of the G/S meter (Milham and Morgan, 2008).

Other methods in reducing dirty electricity from the indoor environment is by removing and replacing electronics and devices that produce non-linear loads such as computers, plasma televisions, energy efficient appliances, energy efficient lighting (i.e. compact fluorescent bulbs), transformer based dimmer switches, and repairing loose wires that cause arching on electrical conductors (Havas, 2000). Computers and energy efficient appliances can be placed on separate circuits to avoid spreading the dirty electricity throughout the building. Compact fluorescent bulbs can be replaced with low wattage incandescent bulbs or other approved LED bulbs that do not produce dirty electricity, and transformer based dimmer switches can be replaced with regular light switches or an approved non-transformer based dimmer switch. Electronic exercise machines such as treadmills should be avoided.

Since high frequency dirty electricity can travel along the electrical distribution system in and between buildings and through the ground, humans, trees, and other conducting objects in contact with the ground become part of the circuit (Milham and Morgan, 2008). If electrical wiring comes in contact with trees that are conducting dirty electricity, it can travel along the wiring and into the building. In one study, it was found that a man being monitored with EKG patches while wearing shoes, standing at the kitchen sink, had high frequency currents oscillating up one leg and down the other between the EKG patches (Havas and Stetzer, 2004).

Although not demonstrated scientifically, it has been suggested that dirty power levels are usually higher in environments with high levels of 60Hz magnetic fields and many electronic devices which generate magnetic fields also inject dirty power into the utility wiring, thus, magnetic fields may be a surrogate for dirty power exposures (Milham and Morgan, 2008). In this study, this hypothesis will be considered if high levels of magnetic fields are present during the field studies.

3 Design Criteria, Strategies and Priority

3.1 Integrated Design Approach

A sustainable residential renovation must meet the criteria of being energy sensitive (i.e. low site and source requirements), durable, provide a high quality healthy indoor environment, and use building materials that can be reclaimed and reused, recyclable, and/or purchased locally. Overall, the renovation should have a low negative impact on the environment while providing a superior healthy indoor environment for the occupants. This paper focuses on minimizing the EMF pollution in an integrative manner while being sensitive to the parallel goals of the project.

Reducing electromagnetic pollution exposure within an indoor built environment requires an integrated design approach that merges energy-efficient design solutions with electromagnetic shielding. This can be accomplished with careful selection of building materials, wiring, lighting, mechanical systems and appliances, which reduce or eliminate EMF pollution.

3.2 Criteria for EMF Pollution Control

Electromagnetic pollution comes from a variety of sources from interior and exterior locations and devices which requires different solutions to either shield or reduce exposure. In any built environment, there is a criterion for field testing, a performance requirement, and functional requirement that must be met to achieve a safe indoor environment. The following summarizes the criteria for EMF pollution control:

3.2.1 Criteria for Testing

There are five aspects of EMF pollution control that must be achieved to reduce EMF pollution from the indoor environment:

1. **AC Electric Fields:** sources that produce electric fields include high voltage transmission lines, low voltage distribution lines, cables, wiring, outlets, fixtures, switches, electronics, appliances, and coiled beds.
2. **AC Magnetic Fields:** sources that produce magnetic fields include high voltage transmission lines, low voltage distribution lines, overhead and underground cables, railways, transformers, motors, imbalanced conductors (net current), electronics, and appliances.
3. **Ground Current (GC) and Contact Current (CC):** electricity flowing through the ground can travel into buildings via conducting sources such as the plumbing system.

Other sources include steel components in beds, mattresses, furniture, appliances, PV panels, steel stud framing, and building materials.

4. **Radio Frequency Radiation:** sources include AM/FM radios, FM TV, transmitters, radar systems, satellite systems, mobile radio, paging systems, cell phones, 2.4 GHz and 5.8 GHz DECT phones, baby monitors, Wi-Fi (wireless internet), WLAN, broadcast and cell phone antennas and most wireless devices.
5. **Dirty Electricity:** sources that generate dirty electricity include computers, variable speed motors, television sets, entertainment units, energy efficient light (i.e. compact fluorescent bulbs), energy efficient appliances, dimmer switches, power tools, arcing on hydro wires, cell phone antennas, broadcast antennas, and neighbours.

3.2.2. Performance Requirement

Measurable limits based on the precautionary principal has been developed by the BauBiologie Maes, an organization of scientists and medical doctors, from their guideline *Building Biology Evaluation Guidelines for Sleeping Areas (2008).* The following categories define the level of action required based on the measurable limits:

No Concern: *This category provides the highest degree of precaution. It reflects the unexposed natural conditions or the common and nearly inevitable background level of our modern living environment.*

Slight Concern: *As a precaution and especially with regard to sensitive and ill people, remediation should be carried out when it is possible.*

Severe Concern: *Values in this category are not acceptable from a building biology perspective and requires action. Remediation should be carried out soon. Numerous scientific studies indicate biological effects and health problems within this reference range.*

Extreme Concern: *These values call for immediate and rigorous action. In this category international guidelines and recommendations for public and occupational exposures may be reached or even exceeded.*

In the absence of an international consensus on EMF exposure limit guidelines, the *Building Biology Evaluation Guideline for Sleeping Areas (2008)* was the most appropriate reference for this research since the values are based on levels which can cause biological effects.

Table 3.1 lists the upper exposure limits that will be used for this research (left) and can be compared to some international exposure limits (right) which clearly shows the great difference between the two.

Table 3.1: Exposure Limits

EMF Pollutants	Units	No Concern	Slight Concern	Severe Concern	Extreme Concern	International Public Exposure Limits
*AC Electric Fields	V/m (kV/m)	< 1 (0.001 kV/m)	1 – 5 (0.001-0.005 kV/m)	5 – 50 (0.005-0.5 kV/m)	> 50 (>0.5 kV/m)	INCIRP(1998): 5000V/m (4.17 kV/m) IEEE (2002): 5 kV/m
*AC Magnetic Fields	Milligauss (mG)	< 0.2	0.2 - 1	1 - 5	> 5	INCIRP(1998): 833mG IEEE (2002): 9000 mG
*Radio Frequency Radiation	Power Density (μW/m^2)	< 0.1	0.1 - 10	10 - 1000	>1000	INCIRP: 9 W/m^2 (9,000,000 μW/m^2) Canada: 5 W/m^2 (5,000,000 μW/m^2) Bio-Initiative: 1000 μW/m^2 outdoor
*Ground Current (GC) or Contact Current (CC)	DC magnetic (mG), & DC electric (mV)	<10 mG <10 mV	10-50 mG 10-100 mV	50-200 mG 100-1000 mV	>200 mG >1000 mV	None
** Dirty Electricity	GS	<30	30 -50	>50	>100	None

(Source: *Building Biology Evaluation Guidelines for Sleeping Areas, 2008; **Havas, 2000).

Electric field strength is measured in volts per meter (V/m) or in kilovolts per meter (kV/m). 1 kV = 1000 V.

Magnetic fields are measured in units of gauss (G) or tesla (T). Gauss is the unit most commonly used in North America. Tesla is the internationally accepted term. 1T = 10,000 G. Since most environmental EMF exposures involve magnetic fields that are only a fraction of a tesla or a gauss, these are commonly measured in units of microtesla (μT) or milligauss (mG). A milligauss is 1/1,000 of a gauss. A microtesla is 1/1,000000 of a tesla. 1 G = 1,000 mG; 1 T = 1,000,000 μT. To convert a measurement from microtesla (μT) to milligauss (mG), multiply by 10. 1 μT=10 mG. (Source: EMF Rapid, 2002)

Radio Frequency Radiation is measured in microwatts per square meter (μW/m^2) or (W/m^2).

Dirty electricity is a measure of dV/dT read by the G/S meter and is defined as GS (Graham/Stetzer) units.

3.2.3 Functional Requirement

The building occupants must be able to function within an environment that does not inhibit their routine tasks such as cooking, laundry, office work, school work, entertaining, etc., while not being exposed to EMF pollutants that can be produced by common household electronics, appliances, and building systems. The occupants must also be able to function in an environment with healthy air and light quality, and a healthy heating system which reduces indoor air contaminants and uncomfortable cold spots throughout the house while not producing EMF pollutants. These functional requirements will assist in designing the home with reduced EMF pollutants.

3.3 Design Strategies to Reduce EMF Pollution

The first step in developing an energy-efficient and healthy indoor environment with reduced EMF pollution is to meet the following criteria:

- Reduce Electricity Consumption
- Eliminate Wireless Technology
- Reduce Ground and Contact Current
- Use Building Materials to Reduce EMF Pollution
- Use Building Systems to Reduce EMF Pollution

3.3.1 Reduce Electricity Consumption

Reducing electricity consumption may not always reduce EMF exposure; in fact, using energy efficient devices and appliances can generate harmful EMF pollutants that can spread all throughout the building. This design strategy is to reduce electricity consumption by using non-EMF polluting energy efficient devices and appliances, and avoiding electricity usage as much as possible in order to reduce EMF exposure from the indoor environment. Increased use of electronics can increase the level of dirty electricity within the building as well as electric and magnetic field exposure.

Therefore, energy efficient appliance and devices which are known to generate EMF pollutants such as dirty electricity should be avoided (i.e. compact fluorescent lighting, dimmer switches, transformers, variable speed motors, plasma TV’s, treadmills); or shielded by placing them on separate circuits to avoid spreading the dirty electricity throughout the building (i.e. front loading washer/dryers, and computer/printer stations); or reduce electricity usage significantly (i.e. air dry clothes instead of using a dryer, hand wash dishes instead of using a dishwasher, use one fridge only per household, unplug electronics when not in use). Table 3.2 summarizes strategies to reduce electricity consumption in the home:

Table 3.2: Strategies to Reduce Electricity Consumption and EMF Pollutants

EMF Pollutant	Strategies to Reduce Electricity Consumption & EMF Exposure	Alternative Solutions
AC Electric and Magnetic Fields	• Unplug electronics and appliances when not in use. • Avoid using microwave ovens, clothes dryer, dishwasher, electric clock radios, electric blankets, electric heaters, electric doorbells, electric lawn mower, and air-conditioning units. • Shut off power during sleep hours in designated zones using Demand Switches. • Avoid living near high voltage transmission lines, low voltage distribution lines, and transformer boxes.	• Use a gas stove. • Use a gas fireplace. • Air dry clothes. • Use non-electric lawn mower. • Use candles for illumination. • Use natural ventilation during cooling season. • Incorporate passive solar design or daylight harvesting design strategies, including thermal mass, to reduce artificial lighting and heating demand. • Design for a flat roof structure for a potential green roofing system to reduce summer cooling loads and for shielding exterior sources of electric fields & RF.
Dirty Electricity	• Avoid using compact fluorescent lighting, dimmer switches, transformers, variable speed motors, plasma TV's, treadmills. • Avoid living near cell phone and broadcast antennas as it may bring in more dirty electricity into the home. • Install approximately 20 GS filters throughout an average sized single family dwelling.	• Use low-wattage incandescent, halogen, or LED light bulbs. • Use dimmer switches with built in filters. • Use LCD or LED TV's. • Exercise outdoors.

3.3.2 Radio Frequency Radiation: Eliminate Wireless Technology

The most effective way in reducing radio frequency radiation within the home is by eliminating wireless technology altogether. With the rapid demand and usage of wireless communication technology available today, eliminating wireless technology may appear unreasonable. However, alternative communication technology solutions are available without being exposed to radio frequency radiation such as using landline phones, cabled internet, and voice activated baby monitors.

Radio frequency radiation can be controlled within the indoor environment to some extent; however, it is more difficult to reduce exposure in the outdoor environment since wireless technology is being used by almost everyone and cell phone antennas are a more common sight in open fields, along highways, on top of high-rise residential buildings and commercial buildings. For outdoor shielding, it is recommended for those who are sensitive to this type of EMF pollution to shield themselves using radio frequency radiation protection garments (www.lessemf.com). Table 3.3 summarizes strategies to reduce radio frequency radiation within the home:

Table 3.3: Strategies to Reduce Radio Frequency Radiation

EMF Pollutant	Strategies to Reduce Radio Frequency Radiation	Alternative Solutions
Radio Frequency Radiation	• Do not use Wi-Fi internet or wireless printers and mouses. • Do not use 2.4 GHz or 5.8 GHz DECT cordless phones. • Reduce usage of cell phones, blackberries, baby monitors, satellite dishes, and other wireless technology. • Do not use wireless technology within a conducting space where radio waves can reflect off surfaces (i.e. cars, metal surfaced rooms). • Avoid living near cell phone and broadcast antennas.	• Use cabled internet, printers, and mouses. • Use landline phones. • Protect cell phones and blackberries with EMR shielding holders/cases. • Wear shielded EMR garments.

3.3.3 Reduce Ground and Contact Currents

If ground currents do not exist on the property, then precautionary measures should be taken to avoid its entry into the building in the future. It can enter through conducting materials such as the city plumbing system and spread throughout the buildings metal plumbing system. Table 3.4 summarizes how to avoid ground and contact currents from entering the building:

For this project, a dielectric coupler was installed where the plumbing system enters the building from the exterior to eliminate ground current from entering into the house via the copper plumbing system. Also, the use of metal framed furniture was avoided to reduce potential contact current.

Table 3.4: Strategies to Reduce Ground and Contact Currents

EMF Pollutant	Strategies to Reduce Ground & Contact Currents	Alternative Solutions
Ground and Contact Currents	• Avoid using steel framed furniture and objects which can conduct currents. • Avoid improper grounding of electrical system.	• Use non-steel framed furniture. • Install a dielectric coupler on the copper pluming line to stop currents from flowing throughout the building.

3.3.4 Building Materials to Reduce EMF Pollution

Studies have shown that common building materials can attenuate, transmit, reflect, and absorb radio frequency radiation (Stone, 1997, Dalke, 2000; Habash, 2002; Minke, 2007; Alejos, 2008; Gratton, 2008; Kim, 2010). Building materials such as brick, concrete blocks, conductive concrete, reinforced concrete provide good attenuation to radio frequency signals and reduce transmission by absorption; the signal attenuation (dB/mm) increases with increasing signal frequency which was tested between the frequency range of 0.5 GHz and 8 GHz with concrete providing the strongest absorption levels (Stone, 1997). Common residential building materials such as plywood, wood studs, glass and drywall have greater transmission levels; the signal loss per unit thickness is proportional to the material density (Stone, 1997).

Low frequency electric fields can be shielded by conducting objects, including the ground, most building materials, trees, humans and animals (Kheifets et al., 2010).

For this project, the exterior two-wythe brick structure was restored (approximately 200 mm in thickness) which can provide significant absorption to radio frequencies as the signal strength increases. It can potentially absorb approximately 50% to 60% in the frequency range of 0.5 to 2 GHz respectively; and 85% to 98% in the 3 to 5 GHz; and 98% to 85% from 5 GHz to 8 GHz (Stone, 1997).

In general, sustainable or “green” building methods and systems have shown to effectively shield EMF pollution. For example, the sustainable approach to renovating this house was to restore the brick structure instead of demolishing; this in turn provides EMR shielding. Also, designing a flat roof system provides the option to install a green roof system which can reduce heat island effect and reduce heating and cooling costs, while providing EMR shielding if a cell phone antennae is unexpectedly erected in close proximity. The low-e window coating saves heating and cooling costs while providing additional EMR shielding by reflecting the radio waves off. Overall, sustainable building choices can provide energy savings, reduce waste to the landfill, and provide excellent EMR shielding. Table 3.5 lists the different building materials that provide shielding against EMF pollutants.

Table 3.5: Shielding Strategies by Careful Selection of Building Materials

EMF Pollutant	Shielding Strategies using Common Building Materials	Alternative Solutions
AC Electric Fields	• Most building materials and vegetation can be used to shield electric fields from exterior low voltage distribution lines.	• Keep a minimum of 4 to 10 feet away from electric field sources.
AC Magnetic Fields	• None other than Mumetal or silicone steels.	• Keep a minimum of 4 feet away from magnetic field sources.
Radio Frequency Radiation	• Using brick and mortar, concrete, reinforced concrete, and conductive concrete to attenuate radio waves. • Use green roof technology for low sloped and pitched roofs to attenuate radio waves. • Use copper roofing and siding to reflect radio waves. • Use low-E coating windows to radio waves.	• Avoid living and/or working in all glass buildings without Low-E windows. • Use conductive paints, conductive fabrics, and copper metal meshes for shielding on the interior side of the building. • Use conductive fabrics containing silver or copper for garments. • Use reflective or absorbing wall coverings for interior use.

3.3.5 Use Building Systems to Reduce EMF Pollution

Building systems include the heating, cooling, and ventilation system (HVAC), electrical system, plumbing system, and lighting system.

3.3.5.1 Mechanical System

The objective of this project is to select a space heating system that is energy-efficient, healthy, and most importantly, does not produce EMF pollution.

The fundamental components of a space heating system include:

- Heat Source: gas, oil, biomass-fired boiler, direct fired air heater, direct gas fired radiant panels.
- Distribution Medium: water, air, steam, or electricity.

- Heat Emitter: radiators, natural convectors, underfloor heating, fan convectors, low-temperature radiant ceiling panels, panel heaters, high-temperature radiant panels, storage heaters, and unit heaters (in modern buildings emitters typically provide both heating and cooling).

Mechanical systems which have variable speed motors (i.e. furnace motors) can produce dirty electricity which can travel throughout the house (Havas, 2000). Since there are so many electric furnaces on the market today, and it is possible that not all furnaces produce dirty electricity, it would be ideal not to use a furnace all together. Electric heating systems should also be avoided to reduce electric and magnetic fields such as electric baseboard heaters and electric underfloor and ceiling systems.

The most healthiest and energy-efficient heating system that does not produce EMF pollution is a hydronic radiant underfloor heating system. It is suitable for domestic applications, areas with low heat loss or either continually or frequently used, or areas with either high ceilings and large areas. The advantage of this system is that it is unobtrusive, provides good space temperature distribution, reduced running cost, and healthy since it does not collect dust. The disadvantage is that heat output is limited, has a slow response to control (radiant only), is sensitive to floor coverings, and repair work is disruptive. Radiant heating systems heat the air indirectly, operates at a lower air temperature than convective systems, and less heat is lost when air escapes form the building. Heat is transmitted from the heat source in the form of electromagnetic rays (mainly infrared), to surrounding cooler objects such as walls, floors, and people. The electromagnetic rays do not absorb surrounding heat, instead, air is heated by contact with the surrounding surfaces just as people transfer radiant heat to cold objects. (Oughton, D.R., Hodkinson, S.L., 2008)

Ideal comfort is to have ‘warm feet and cool head’ which means the temperature at the feet should be warmer than the temperature at the head which can be achieved with a radiant underfloor heating system. With conventional gas fired furnace systems, warm air rises causing discomfort for occupants due to cold feet and stuffiness at the head level. The temperature rise between ankle and head should not exceed 3^{o}C. The temperature of the floor surface should be in the range of 19^{o}C to 29^{o}C to avoid localized discomfort. (Oughton, D.R., Hodkinson, S.L., 2008)

The use of a heat recovery ventilator (HRV) without a variable speed motor can be used for increasing energy-efficiency. As for the cooling system, the use of an air-conditioning system should be avoided or used only absolutely necessary.

For this project, the space heating system includes a gas fired boiler connected to an HRV for energy efficiency, and a hydronic underfloor heating system which includes radiant floor tubing reinforced with steel wire mesh installed throughout the house on all floors. The system is energy efficient, healthy, and produces no EMF pollution.

3.3.5.2 Electrical System

The objective of this project is to select an electrical system that shields against electric and magnetic fields which otherwise radiates from the electrical wires.

The original outdated knob-and-tube wiring was replaced with new electrical wiring, panel, circuits, outlets, and switches. Approximately 300 ft. of flexible steel BX armored cable was reclaimed from the existing house and approximately 700 ft. of additional copper wiring in BX armored cable was utilized throughout the house.

Electrical Wiring and Configuration

For this project, using a conductive flexible steel BX armored cable will eliminate electric field exposure from the wiring since electricity travels along the least path of resistance. The magnetic fields will be eliminated by using copper electrical wiring which contains the live, neutral, and grounding conductors; the opposing currents produce magnetic fields which cancel each other out. Thus, both low-frequency alternating electric and magnetic fields are eliminated from the wiring.

Since electric fields and dirty electricity will continue to radiate from the electrical outlets, switches and light fixtures, the outlets can be strategically located away from sleeping areas to reduce exposure during the day. For additional precaution, the electrical power can be shut off altogether in designated rooms where the most exposure can occur by installing demand switches at the main electrical panel which can be operated by a remote control device. (i.e. bedrooms during sleep hours). For this project, the electrical outlets were located in the corners of the bedrooms away from the beds; however, demand switches were not installed since the electric fields throughout the house were extremely low. Refer to Figure 4.1 for floor plans.

In any renovation or new construction with multiple floors where only the standard ‘Romex’ electrical wiring is utilized, the electrical wires can be installed to run from the top of the house to the bottom of the house via a continuous stairwell where occupants will be least exposed to electric fields; magnetic fields are typically shielded when using standard Romex wiring as a result of opposing currents cancelling out the magnetic fields. For this renovation, although the BX armored cable with copper wiring was used for shielding both electric and magnetic fields, it was also configured to run vertically from the top of the house to the bottom of the house via the stairwell.

Demand Switches

Four demand switches were going to be installed at the main electrical panel in a separate wall mounted box, however because the electric fields were extremely low throughout the house it was not necessary for the demand switches. The purpose of the demand switch is to turn off all power to designated zones from the main electrical panel. Typically, it would be desirable to install one demand switch for every occupied bedroom and can be turned on or off by using a remote control device. Each demand switch can connect to 5 devices in each zone. Power will be turned off in the designated zones during the night when the occupants are asleep to eliminate electric field and dirty electricity exposure radiating from the outlets, switches, and light fixture. Figure 2.15 shows an image of the demand switch below is manufactured by Safe Living Solutions in Ontario and is CSA approved.

Electrical Mast and Panel

Electrical power will enter the house either underground or strung overhead and attached to a post at the service head typically located at the roof of the house. Most older homes built after 1950 will have three wires running to the service head: two power lines, each carrying 120 volts of current, and a grounded neutral wire. Power from the two 120-volt lines may be combined at the main electrical panel inside the home to supply current to larger 240-volt appliances like the clothes dryer or electric water heaters. The power then passes through an exterior electrical meter to measure electrical consumption before entering the home at the main electrical panel typically located in the basement.

For this project, the exterior steel service head is located on the northwest side of the second floor bedroom roof/ceiling (refer to Figure 4.1 for floor plans). The electric fields can be shielded by the building, however, the magnetic fields would radiate into the bedroom at the sleeping area. Although the strength of the magnetic fields drops drastically four feet from the source, magnetic shielding may be required. After the first electrical inspection conducted by a representative of Electrical Safety Authority (ESA), it was determined that the entry point could be lowered to approximately 4.9 meters above grade, to approximately the same level as the second floor master bedroom. Results of the post-renovation field survey indicated that magnetic field shielding would be required at this location.

The electrical panel for this project is located in the basement at the northwest corner within an enclosed room approximately 8 ft. wide by 5 ft. The basement walls are constructed with steel studs and gypsum board. The walls in the electrical room provide a good shield against electric fields from entering into other rooms of the basement. Results of the post-renovation field survey indicated that the magnetic fields dropped drastically within 4 ft. in each direction and did not enter the main living area of the basement, the magnetic fields did radiate up to the ground floor living room above. It was also observed that the combined magnetic fields from the electrical panel and HRV may have contributed to an isolated “hot spot” attenuated at the bottom of the basement stairs due to the bulk of the BX armored cable at this location and steel stud framing. Further research on magnetic field behavior with steel frame construction would be required.

Electrical Circuits

The Ontario electrical code limits up to 12 devices per electrical circuit with a source voltage of 120-volts. A separate circuit would be required for the clothes dryer and fridge which require a high source voltage of 240-volt. Separate circuits can also been installed for devices that produce harmonic distortion (dirty electricity) such as computer and printer stations. For this project, battery operated laptop computers are use instead of plugged-in desktop computers.

Electrical Grounding & Plumbing

Houses in a neighborhood are all connected to the same electrical distribution system and city sewer systems. This can cause a number of problems if any of the houses are producing either dirty electricity within their homes or if the grounding system is incorrect causing an imbalance of “stray” current in the electrical and/or plumbing system. Most electrical systems in houses are grounded to the plumbing system thereby making a connection between the neighborhood electrical systems and plumbing systems.

Plumbing current can travel throughout the house radiating electric and magnetic fields. For this project, a dielectric coupler has been installed on the municipal water supply, just as it enters the house and after the main electrical ground. There can be no plumbing current from occurring.

Dirty electricity typically rides along the electrical wires and throughout the house if it is not filtered. It has been recommended to install four electrical outlets at the electrical panel. Two are to be designated to install two GS filters to reduce the level of dirty electricity from entering the house and the other two as extra. An additional 18 filters have been installed throughout the house to filter out the dirty electricity.

3.3.5.3 Lighting System Results

Traditional residential incandescent light bulbs are inefficient by consuming a large amount of electricity while generating approximately 94 to 96% wasted heat energy (Natural Resources Canada, 2006). Electricity is generated by burning fossil fuels which produces harmful greenhouse gas emissions which contribute to climate change. Thus, in April 2007, the Government of Canada announced that it will introduce national standards for lighting efficiency and start phasing out inefficient lighting by 2012. Inefficient incandescent bulbs are now being replaced with new energy efficient technology including Energy Star compact fluorescent bulbs (CFL's) and light emitting diodes (LED's).

An average Canadian home has around 26 light fixtures, which has about an average cost of $200 annually for electricity (Natural Resources Centre, 2006). Energy star approved bulbs have to meet minimum light outputs and meet strict efficacy or lumen-per-watt requirements (Natural Resources, 2006). Replacing only 5 bulbs with Energy Start compact fluorescent bulbs (CFL's) in high use fixtures (lights on more than 3 hours a day) would save approximately $30 a year, and replacing all the household bulbs with CFL's would save approximately $125 a year. If every Canadian household replaces just one incandescent bulb with an Energy Start CFL, Canadians would reduce GHG by 400,000 tones which is equivalent to taking 70,000 cars of the road for a year and save more than $73 million a year in energy costs (Natural Resource Centre, 2006).

According to recent studies, CFL's contain mercury content, emit UV radiation, emit radio frequency radiation, and some generate dirty electricity which is making people ill with symptoms including migraines, skin problems, epilepsy, and electrical sensitivity (Havas, 2008). The mercury in the bulbs emit UV radiation when it is electrically excited which interacts with the chemicals on the inside of the bulb to generate light. Tube fluorescent bulbs have diffusers that filter the UV radiation, but the new CFL's do not have these diffusers, thus exposing people to UV radiation. UV radiation has been linked to skin cancer and various skin disorders (Environment Canada, 2010).

CFL's operate in the range of 24 to 100 kHz in the radio frequency range which generates dirty electricity or poor quality power throughout the building wiring. According to Hydro One, poor quality disturbance takes many forms including voltage sag, phase unbalance and voltage swells, transient disturbances, momentary interruptions, and long-term steady state waveform distortions; CFL's produce transients (Havas, 2008). Not all CFL's generate the same level of dirty electricity (Havas, 2008). However, if every light bulb in a home is replaced with a CFL, as recommended by Natural Resources Canada, occupants will not only be exposed to radio frequency radiation, UV radiation, but it will also generate dirty electricity or poor quality power which has been shown to cause illness (Havas, 2004).

For example, General Electric (GE) manufacture electronically-ballasted CFL operating in the 24-100kHz frequency range which is within the radio frequency band, and is classified as Intermediate Frequency by the World Health Organization which studies show to cause biological effects (Havas, 2008). On the back of every package is a warning that these bulbs can cause interference with wireless technology operating between 0.45-30MHz.

Precautionary measures have to be taken if a bulb breaks including wearing rubber gloves, opening the window, and double-bagging the broken pieces (Havas, 2008). CFL's also need to be disposed at a toxic waste facility just as paint, batteries, thermostats, and other household chemicals (Natural Resources Canada website on consumer questions (7)).

Light emitting diodes (LED's) and Halogen bulbs use a different technology that contains no toxic chemicals and are energy efficient. The cost of these bulbs are much greater than CFL's. For the purpose of this study, only incandescent light bulbs, LED's, and Halogen light bulbs were tested and measured to determine if they contribute to dirty electricity (Table 3.6).

The Home Depot Canada only stocks the Philips brand, therefore, all the residential Philips ambient light bulbs were tested at different wattages including incandescent, LED's, and Halogen. The Sylvania, Noma, and GE brands were obtained from Canadian Tire and selection was very scarce. The DDI LED bulb was specially designed and manufactured through a Canadian engineer company, Digital Design Inventions, developing durable, energy efficient, low-cost LED bulbs that and produces no dirty electricity.

Table 3.6: Measured Light Bulbs for Dirty Electricity

Ambient Light Bulb Brand	**Cost**	**Specifications**			**Effect on G/S Meter**
		W=watts	**L=lumens**	**Hr=hours**	
Philips Soft White Incandescent	$2.98	25 W	235 L	3000 Hr	No Effect
Philips Soft White Incandescent	$2.78	40 W	475 L	1500 Hr	No Effect
Philips Soft White Incandescent	$2.78	60 W	830 L	1500 Hr	No Effect
Philips Soft White Incandescent	$2.78	100 W	1440 L	1500 Hr	No Effect
Philips Bright White Halogena	$4.39	60 W	840 L	3000 Hr	No Effect
Philips Bright White Halogena	$4.39	100 W	1670 L	3000 Hr	No Effect
Phillips CFL		5 W (=25W)			Slight Increased

					Effect
Philips Soft White LED	$19.98	7 W (=25W)	155 L	40,000 Hr	Slight Increased Effect (20+ GS)
Sylvania Ultra LED	$39.99	8 W (=40W)	350 L	25,000 Hr	Slight Increased Effect (20+ GS)
DDI Soft White LED	$19.99	5 W (=40W)	??? L	18,000 Hr (to 30,000 Hr)	No Effect
GE Soft White Incandescent	$1.99	15 W	110 L	2500 Hr	No Effect
GE Soft White Incandescent	$1.99	25 W	210 L	2500 Hr	No Effect
GE Soft White Incandescent	$1.99	150 W	2780 L	750 Hr	No Effect
Noma Soft White Halogen	$6.99	40 W (=29 W)	345 L	3000 Hr	No Effect
Noma Soft White Halogen	$6.99	100 W (=72W)	1100 L	3000 Hr	No Effect

Table 3.6: G/S meter effect on various ambient residential light bulbs on the market. W=watts, L-lumens, Hr=hours.

The results of the measured light bulbs showed that most of the incandescent bulbs did not affect the G/S meter, thus, did not contribute to poor quality power. Although these bulbs are safer and healthier than CFL’s, they are very inefficient, they contribute to climate change, and they are also being phased-out starting in the year 2012. The Halogen light bulbs were slightly more expensive than the incandescent bulbs due to better efficiency and generally had no effect on dirty electricity. The LED light bulbs tested included Philips 7W (25W equivalence), Sylvania 8W (40W equivalence), and DDI 5W (40W equivalence. The Philips and Sylvania LED bulbs had a slight increased effect on the G/S meter (approximately 20 G/S increase), while the DDI LED bulb had no effect. It was found that the Sylvania and DDI LED bulbs were more comparable in terms of the wattage and lumens rating. However, the wattage of the DDI LED bulb was measured using an energy meter which indicated that its actually operating wattage was 2W (not 5W), was less expensive, and had no effect on the G/S meter and did not produce dirty electricity.

For this project, a combination of low wattage incandescent, halogen, and DDI LED’s were installed throughout the house. Also, compatible radio frequency filtered Levitron dimmer switches were also used in this renovation. Table 3.7 summarizes the design strategies to reduce EMF pollution through careful selection of building systems.

Table 3.7: Building Systems to Reduce EMF Pollution

EMF Pollutant	Shielding Strategies by Careful Selection of Building Systems	Alternative Solutions
AC Electric Fields	• Use conductive flexible steel BX armored cable with electrical conductor's encased within the cable.	• Replace outdated knob-and-tube wiring.
AC Magnetic Fields	• Use Romex electrical wiring encased in BX armored cable.	• Ensure proper grounding of neutral conductor and copper ground to avoid net currents.
Dirty Electricity	• Use a hydronic underfloor heating system supplied from a gas fired boiler. • Use low wattage incandescent bulbs, halogen bulbs, or LED bulbs.	• Avoid furnaces that use a variable speed motor. • Avoid using compact fluorescent light bulbs.

3.4 Priority Rating for Strategies

The different design strategies can be applied for renovations and new construction of residential houses. However, in an existing house, not all design strategies can be applied due to the nature of the building or not being cost-effective. Therefore, the following priority rating has been developed for existing buildings to significantly reduce EMF pollution according to the level of action required and cost:

Priority 1: Immediate action by home owner (low cost).

Priority 2: Conduct EMF survey. Planned action by home owner and contractors (moderate cost).

Priority 3: Major renovation and/or new construction (moderate to high cost).

Table 3.8 on the following page is a list of action required according to the priority rating. Priority 1 are precautionary actions which can be conducted without an EMF survey or hiring contractors to do work. Priority 2 are precautionary actions required after the completion of an EMF survey to determine the extent of work required. Priority 3 are design strategies for major renovations and new construction projects and generally merges design strategies for an reduced EMF pollution and energy efficiency. Each level increases in cost according to the amount of work necessary.

Table 3.8: Priority Rating for Strategies based on Level of Action and Cost

EMF Pollutant	Priority 1	Priority 2	Priority 3
AC Electric Fields	• Unplug electrical devices when not in use. • Keep electrical cords away from feet. • Avoid electrical heating systems.	• Install demand switches in dedicated zones.	• Install flexible steel BX armored cable with Romex electrical wiring.
AC Magnetic Fields	• Keep back from appliances and devices when on. • Discard or reduce usage of clothes dryer; or do not run dryer during sleep hours if adjacent to a bedroom. • Discard the microwave; do not operate adjacent to living areas.	• Install Mumetal or Silicone Steel absorbing metals in areas of high magnetic fields if adjacent to living areas (effective up to 100 kHz). • Relocate exterior electrical mast if adjacent to sleeping areas.	• Install flexible steel BX armored cable with Romex electrical wiring.
Radio Frequency Radiation	• Replace all wireless DECT phones with landline phones. • Remove all wireless devices and/or reduce wireless usage.	• Install cabled internet. • Install conductive window shield coating. • Use conductive paints, fabrics, or other materials for interior shielding.	• Use brick and mortar, and concrete for new construction. • Install green roof system. • Install copper mesh for maximum shielding on interior side of building. • Install low-E windows.
Ground and Contact Current		• Install dielectric coupler on municipal water supply at entry point and after electrical ground.	
Dirty Electricity	• Remove all CFL's; use incandescent, halogen, or LED bulbs. • Discard treadmills, plasma TV's, dimmer switches.	• Install GS filters. • Install separate circuits for dedicated areas for computer/printer work and power tool work.	• Install a gas fired boiler connected to a hydronic underfloor heating system and heat recovery ventilator (HRV).

4 Case Study: Description of Model House, Results, and Analysis

4.1 Description of Model House

Design strategies to reduce EMF pollution from the indoor environment have been implemented in a sustainable renovation of a three-store, single-family dwelling, constructed circa 1909, as part of Renovation 2050 – a sustainable renovation initiative located in Toronto, Ontario. The original house was approximately 1900 square feet with an 8 inch masonry structure and concrete block foundation, no insulation, original single-pane windows, old knob-and-tube electrical wiring with breaker panel, and an outdated gas furnace and boiler. The house was unoccupied and in an unlivable poor condition prior to the renovation. Refer to Appendix A for some photos of the project.

The objective of this major "sustainable" renovation was to develop a high performance, durable, energy-efficient building with a superior indoor environment by eliminating or reducing indoor environmental pollutants, specifically EMF pollution. During the renovation, building materials were either reclaimed or restored from the house such as the masonry structure, trim, doors and some electrical steel BX armored cable. The approach to this sustainable renovation required an integrated design process involving careful selection of building envelope materials, lighting system, HVAC system, and electrical system. Table 4.1 shows the house parameters before renovation:

Table 4.1: House Parameters before Renovation

House Parameters Before Renovation	
Size	1900 ft^2: unfinished basement, ground floor living/dining and kitchen, second floor 2 bedrooms and bathroom, third floor open attic.
Above Grade Wall Construction	2"x4" frame, 16" spacing, lath and plaster interior walls, 8" brick exterior.
Below Grade Wall Construction	Hollow concrete blocks.
Roof Construction	Asphalt shingles on pitched roof structure; plywood sheathing; 2"x10" frame at 24" spacing; lath and plaster interior.
Windows	Single-pane, uninsulated windows in wood frames.
Appliances	Original electric double-oven range, outdated refrigerator.
Lighting	Incandescent light bulbs.
Electrical System	Knob-and-tube wiring with breaker panel.
Heating Unit	Outdated natural gas furnace. Fan w/o HRV.
Cooling Unit	None.
Domestic Hot Water Heater	Outdated natural gas conventional tank.

The new floor area of this house is approximately 2500 square feet which includes a 200 square foot ground floor extension and a 450 square foot third floor extension. The original masonry wall has been restored and a new interior framing system was installed. An application of closed-cell spray foam insulation was installed in various thicknesses to the interior side of the foundation walls, above grade masonry walls, and the underside of the roof framing. A new roof, windows, electrical, plumbing and mechanical systems were installed.

This sustainable renovation is intended to be a model house for industry professionals in pursuit of sustainable residential renovations (www.ryerson.ca/richman).

Figure 4.1 on the following page shows the floor plans of the modeled home and Table 4.2 shows the house parameters after renovations house parameters:

Table 4.2: House Parameters after Renovation

House Parameters After Renovation	
Size	2500 ft^2: finished basement; ground floor living/dining, kitchen with 200 ft^2 extension; second floor 2 bedrooms and 2 bathrooms; third floor 2 bedrooms, 1 bathroom and 1 laundry room.
Below Grade Wall Construction	16mm gypsum wall board c/w interior finish; 150 mm 2lb closed-cell polyurethane spray foam insulation; 38mm x 63mm steel studs on 610mm c/c spacing offset by 85mm from foundation wall; 510mm x 200mm cast-in-place (25 MPa) concrete (existing); 510mm x 200mm cast-in-place (25MPa) concrete c/w 2-15 continuous reinforcement (new).
Above Grade Existing Wall Construction	16mm gypsum wall board; 150mm 2lb closed-cell polyurethane spray foam insulation RSI 7.04 (R40); 38mm x 63mm wood studs on 610mm o/c spacing offset 85mm from foundation wall; existing 200mm brick masonry.
Above Grade New Wall Construction	16mm gypsum wall board c/w interior finish; 38mm x 63mm wood studs on 610mm o/c; 75mm 2lb closed-cell polyurethane spray foam insulation; 38mm x 140mm wood studs on 610mm o/c w/ 2lb closed-cell polyurethane spray foam; 12.5mm ext. grade plywood; spun-bonded polyolefin building paper; cement fibreboard cladding on vertical strapping (drained and vented).
Above Grade Existing Third Floor Wall	Same as above but with existing exterior board-sheathing.
Roof Construction	Flat roof structure (RSI-13/R-76): 16mm gypsum wall board c/w interior finish; 230mm wood rafter filled c/w 2lb closed-cell polyurethane spray foam; 16mm plywood sheathing; 50mm extruded polystyrene; 12.5mm protection board; 2-ply modified bitumen membrane with a reflective surface coating. Sloped roof structure (RSI-10.5/R-60): 16mm gypsum wall board c/w interior finish; 230mm wood rafter filled c/w 2lb closed-cell polyurethane spray foam; existing board sheathing; prefinished metal roof.
Windows	Triple-glazed sealed insulated fixed and operable units with a HEAT MIRROR film with XUV fading protection on exterior pane surface RSI 2.52. (Southwall Technologies). Fiberglass frames.
Appliances	Gas range and electric energy-efficient refrigerator (BOSCH).
Lighting	(20) Low wattage incandescent light bulbs and (20) 50W halogens bulbs. JUNO Downlite fixtures (JUNO Lighting Group). Levitron RF filtered dimmer switches.
Electrical System	300 ft reclaimed BX armored cable and 700 ft additional copper wiring in BX armored cable. 200 V breaker panel. Demand switches not required.
Heating Unit	Hydronic underfloor heating system connected to a gas hot water tank and HRV.
Cooling Unit	Air-conditioning unit (to be used minimally).
Ventilation	Fan with HRV.
Domestic Hot Water Heater	Conventional gas hot water tank.

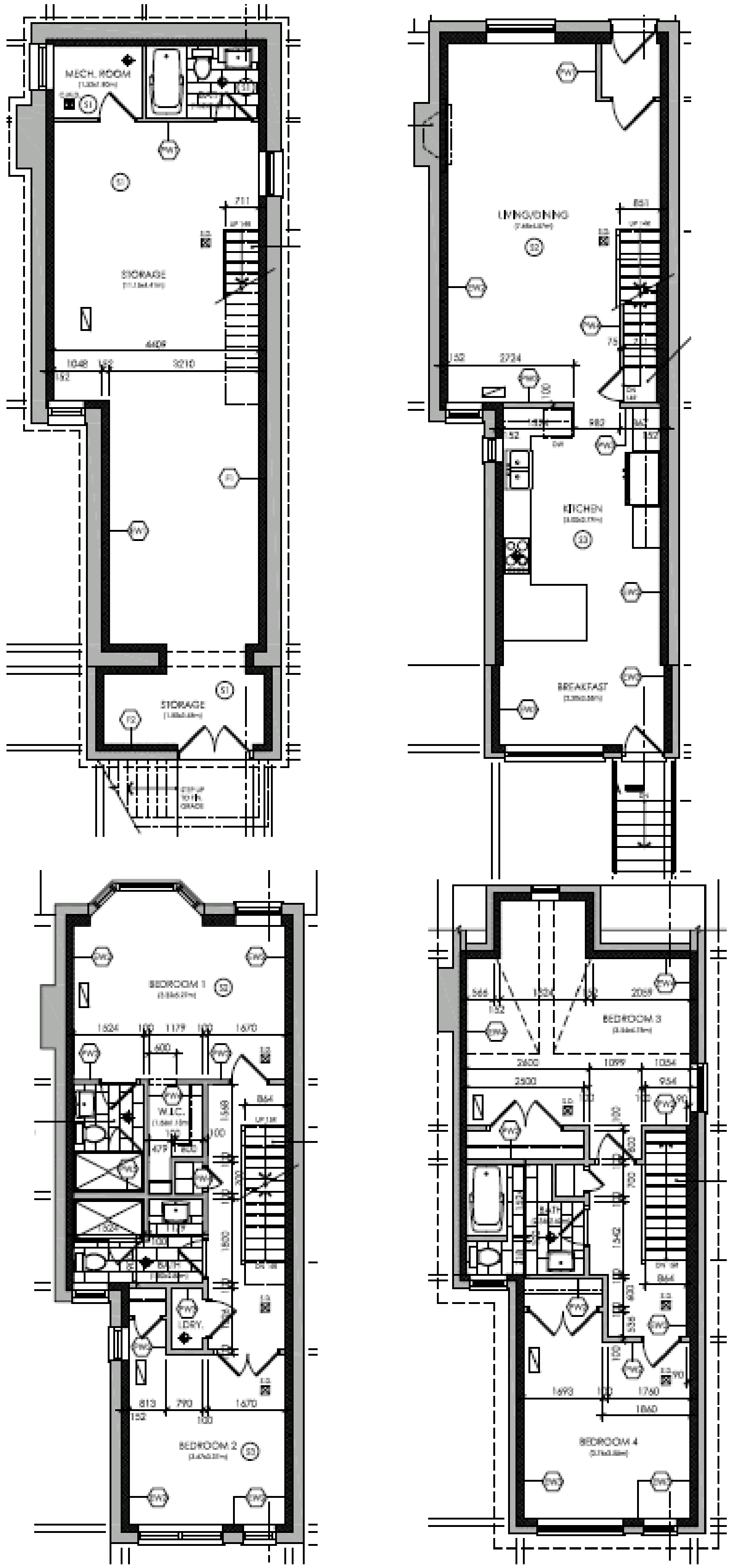

Figure 4.1: Basement floor plan (top left); ground floor plan (top right); second floor plan (bottom left); third floor plan (bottom right).

4.2 Field Review and Results

Routine site visits were conducted to collect spot measurements before, during, and after the renovation. Before renovations commenced, only dirty electricity was measured. During renovations, low frequency EMF and high frequency EMR was measured. After renovations were complete, dirty electricity, power frequency EMF, and radio frequency radiation were measured. Refer to Section 4.2.1 for a list of measuring equipment used, and Section 4.2.2 for field results. Measuring equipment for power frequency EMF and radio frequency radiation was available after renovations commenced only, therefore, results are not available prior to the renovation.

4.2.1 Measuring Equipment

A variety of equipment was necessary to measure the various EMF pollutants (Figure 4.2). Table 4.3 lists the equipment used for this research to measure the various EMF pollutants within the building:

Table 4.3: Measuring Equipment

Measuring Equipment	
AC Electric Fields	Aaronia Model NF-5030 (1Hz to 10MHz)
AC Magnetic Fields	Aaronia Model NF-5030 (1Hz to 10MHz)
Radio Frequency Radiation	Aaronia Model HF-6080 (10MHz to 8GHz) Spectrum Analyzer and with HyperLOG-6080
Dirty Electricity	GS (Graham/Stetzer) Microsurge Meter
Ground and Contact Current	Mastercraft Digital Multimeter with Clamp

Figure 4.2: Aaronia Pro-Bundle 2 Package (left); GS Microsurge Meter and GS Filter (middle); Mastercraft Digital Multimeter with Clamp (right).

4.2.2 Data Analysis

The graphs below show the results of the various measurements (dirty electricity, low frequency electric and magnetic fields, electromagnetic radiation, and ground and contact current) taken before, during and after the renovation of the model house from March to November 2010. The EMF survey was conducted during morning hours under normal occupied conditions.

4.2.2.1 Dirty Electricity Levels: Before and After Renovations

Before the renovation commenced, a GS Microsurge Meter was used to measure dirty electricity throughout the house; the measurements were between 170 to 440 GS units. After the completion of the renovation, the dirty electricity was measured again throughout the house; the measurements were between 230 and 850. The fluctuations in the readings vary throughout the day and are a result of the level of dirty electricity generated by the occupants and neighbouring houses that are connected to the same electrical distribution system. After the installation of approximately 20 filters (5 per floor); one filter installed at the main electrical panel and the remainder installed throughout the house, a dramatic reduction in GS levels occurred to a range of 30 to 50 GS units. Generally, readings below 30 are the target, however readings between 30 and 50 are acceptable, and readings above 50 are an indication that more GS filters are required (Havas and Stetzer, 2004). For this renovated house, the installation of 20 GS filters was adequate. Figure 4.3 show the results of the field measurements of dirty electricity for the model house.

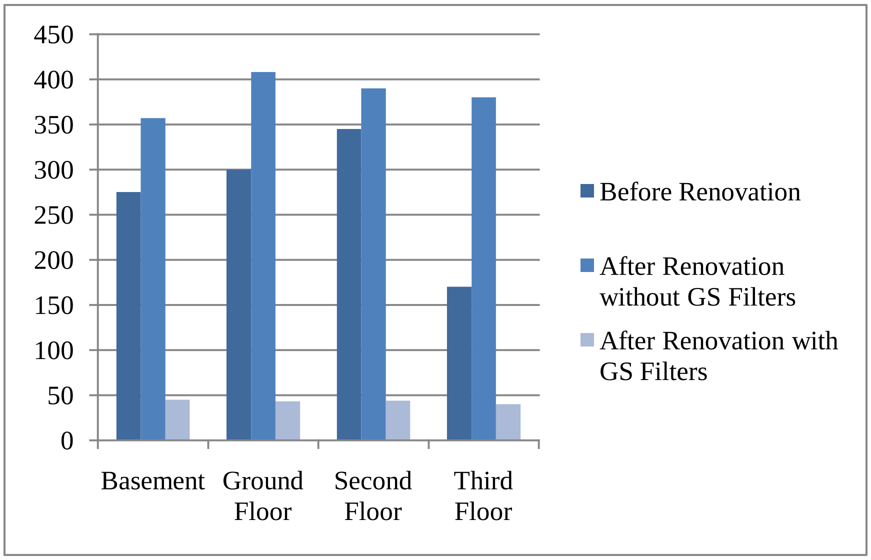

Figure 4.3: Dirty electricity results of model house before and after renovation in GS units.

The differences between the readings before the renovation and after the renovation (without filters) indicate that the reduction of GS units is attributed to the installation of the GS filters only. Although the use of electronics and appliances that contribute to dirty electricity were avoided (i.e. compact fluorescent bulbs, dimmer switches without filters, treadmills, a gas furnace with variable speed motor, and non-battery operated computers), it did not appear to affect the level of dirty electricity in the home since most of it is comes through the electricity distribution system. Refer to Section 4.2.2.5 for dirty electricity results comparing this model house with neighbouring houses.

4.2.2.2 Low Frequency EMF Levels: During and After Renovation

Before the renovation commenced, the house was unoccupied and measuring equipment was not available, therefore, no field data was collected at that time.

During renovations, low frequency EMF and high frequency EMR meters were available to take periodic spot measurements. Electric power was available only at isolated locations in the home, therefore, any unusual measurements of low frequency electric or magnetic fields would be an indication of sources from the exterior only. The average of the results during construction indicated that there were no unusual low frequency electric or magnetic field sources coming in from the exterior (Figure 4.4a and 4.4b). In general, conventional brick and mortar provides good shielding from low frequency electric fields and radio frequencies (Alejos, et al., 2008). The only exterior source of magnetic fields would have come from the electrical mast located at the northwest corner of the third floor; however, no significant magnetic fields were recorded in that location possibly due to the fact that magnetic fields drastically reduce with distance.

AC Electric Fields

After the renovation was complete, low frequency electric and magnetic spot measurements were recorded and the results are show in Figures 4.4.a and 4.4.b. As expected, the electric fields were extremely low between the range of 0.2 and 0.8 V/m which is of no concern to health according to Table 3.1 exposure limits. The low electric fields throughout the house were a result of using BX armored cable to shield the electric fields. With such low fields, it would not be required to install the demand switches in the dedicated bedroom zones to shut of power during sleep hours unless the occupants want to achieve zero electric fields. The use of demand switches is a good alternative in homes where new electrical BX armored cable cannot be installed.

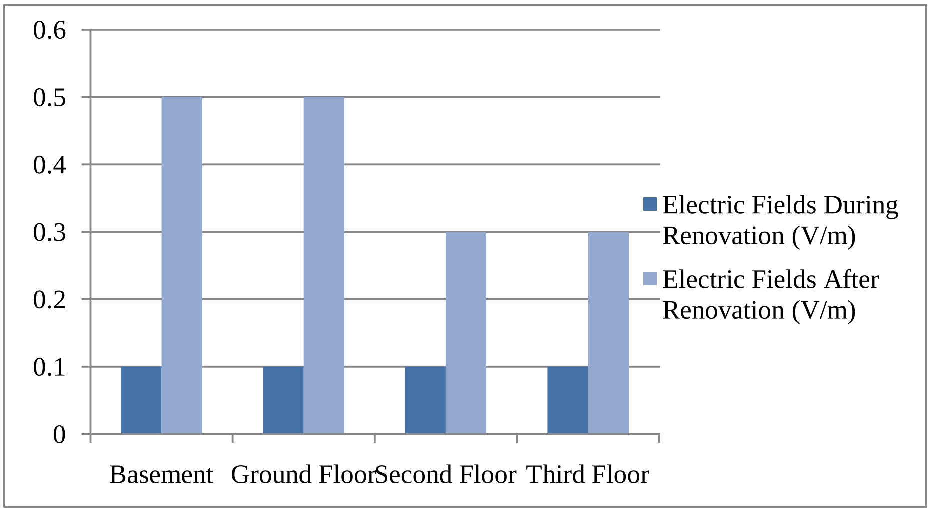

Figure 4.4a: Low levels of AC electric fields during and after the renovation.

AC Magnetic Fields

In general, the twisted copper wire conductors in the BX armored cable cancels out the magnetic fields that would otherwise be present if the conductors were separate (i.e. outdated knob-and-tube wiring). The magnetic field spot measurements were taken throughout the house. It was expected to achieve extremely low levels (below 1.0 mG) throughout the house; however, there were three isolated “hot spots” with higher than normal magnetic field levels. Refer to Table 3.1 for exposure limits. If readings are between 1 to 5 mG there is a severe concern, and if greater than 5 mG there is an extreme concern; in either case shielding or rectifying the cause of the problem is required.

One “hot spot” was located in the basement service room which houses the gas fired boiler, the heat recovery unit (HRV), and the electric service panel. It was expected to have high magnetic field levels within inches of these units and drastically drop with distance. The magnetic fields did drop with distance from approximately 50 mG at 1 inch to approximately 1.2 mG at 6 feet away and very low fields below 1.0 mG were measured in the living space outside the service room. However, readings between 2 and 4 mG in the adjacent bathroom were recorded due to the closer proximity to the service room.

Another “hot spot” was in the basement at the bottom of the stairs below the window. At this location, the bulk of BX armored cable is installed before going vertically up the staircase to the upper floors. The readings ranged between 2.9 and 17 mG just below the window and dropped the higher up the stairs to approximately 1.2 to 1.4 mG. Wherever there is an electric field present around any source carrying voltage whether there is current flowing or not, a magnetic field will be created only when current flows (Riley, 2005). The basement is all steel framed construction and some concentration and attenuation effects have occurred at this particular location where the bulk of the BX armored cable passes through. The magnetic fields radiating from the service room may have also contributed the attenuation effects at this location. Further research on magnetic field behavior with steel cables and steel frame construction would be required.

Another “hot spot” is located on the second floor at the north living room window/wall area. The readings ranged between 2.6 and 7.0 mG (extreme concern) which is most likely coming through the service room located directly below and the exterior service mast located at the floor above.

The final hot spot was located at the third floor northwest wall in the master bedroom where the exterior service wires are located. According to Figure 4.4b, the magnetic fields drop on each higher floor. The twisted copper wiring in the BX armored cable causes the magnetic field to cancel out and the less concentration of BX armored cable in the wood framing reduces the potential for any “hot spots”. It is recommended that these hot spots be shielded with magnetic absorbing materials such as Mumetal or silicone steels.

Refer to Section 4.2.2.5 for low frequency EMF results comparing this finished model house levels with neighbouring house levels.

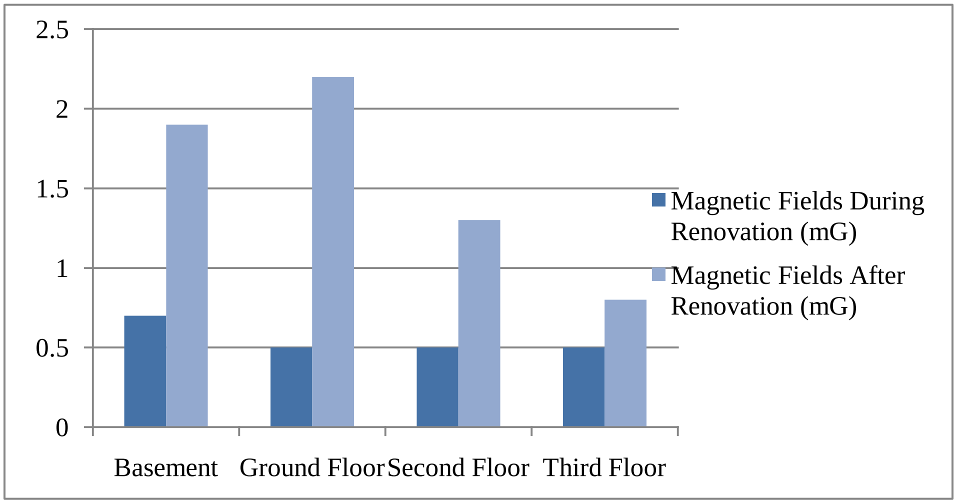

Figure 4.4b: Low levels of magnetic fields (mG) during and after the renovation.

4.2.2.3 Radio Frequency Radiation: During and After Renovation

The results of the high frequency EMR measurements during renovation indicated that there were no significant RF sources coming in from the exterior (Figure 4.5). In general, conventional brick and mortar provides good shielding to high frequency radiation (Alejos, et al., 2008). After the renovation was complete, the shielding effectiveness was marginally better possibly due to the installation of new triple-glazed, sealed insulating units with a conductive HEAT MIRROR film with XUV fading protection coating on the middle pane surface. Conductive coatings on glazing units provide good radio frequency radiation and UV radiation shielding.

Table 4.4 shows the measurable ranges on the Aaronia HF 6080 which corresponds to the Hot Keys on the device:

Table 4.4: Aaronia HF 6080 Hot Keys and Corresponding RF Ranges

Aaronia HF 6080 Hot Keys	Actual Settings on the Aaronia HF 6080
1	VHF 168MHz-215MHz
2	UHF1 450MHz-699MHz
3	UHF2 700MHz-865MHz
4	Wi-Fi 2390GHz-2450GHz
5	TEL 900 MHz-930MHz (Cordless Telephone)
6	2450 (Bluetooth)
7	STL 944MHz-952MHz (Studio Transmitter Link)
8	AVIS 2900GHz-3260 (Automotive Vehicle ID System)
9	ASTLIS 48MHz-82MHz (Assisted Listening)
0	DECT 1885MHz-1885MHz

Figure 4.5 shows on the following page show the results of the average recorded RF levels during and after renovation.

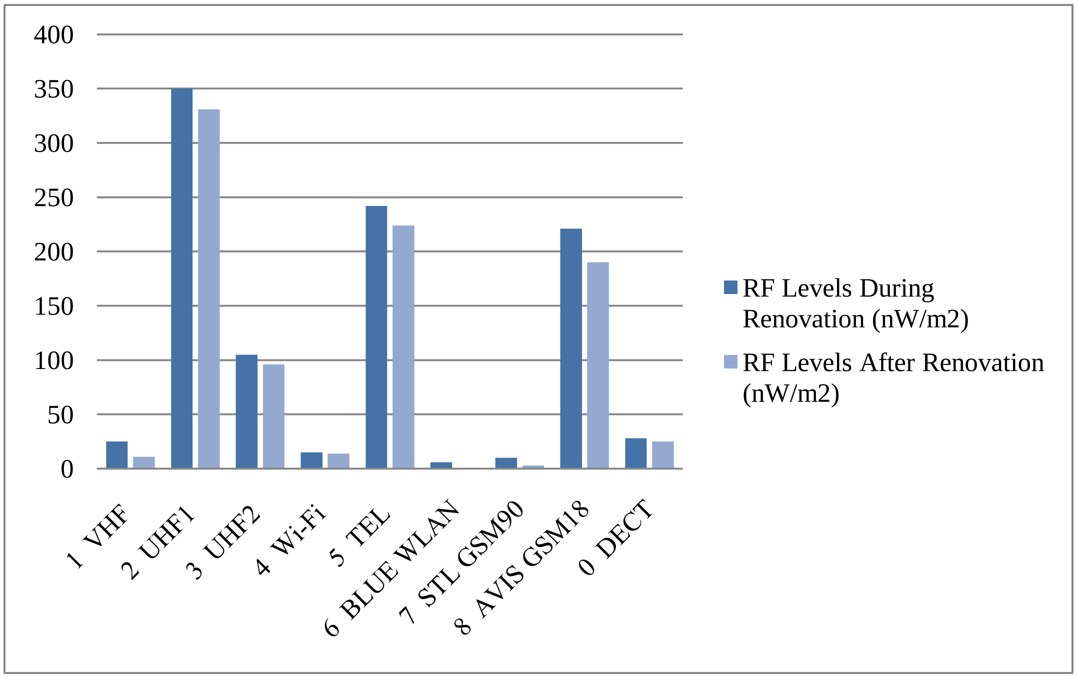

Figure 4.5: Radio Frequency Levels During and After Renovation (nW/m^2).

Health Canada Safety Code 6 states that the exposure limit for EMR exposure within the radio frequency range is 5 to 10 W/m^2 which is based on the upper level at which the radiation can heat body tissue. However, numerous studies have found that biological effects occur at much lower levels (refer to Figure 2.13). Although Safety Code 6 levels are too high, the results for this house are very low and would not produce significant biological effects. It is recommended to conduct annual measurements to ensure safe levels and to determine if additional shielding would be required since wireless communication technology is rapidly changing and cell phone antennas are becoming a more common sight.

Refer to Section 4.2.2.5 for radio frequency radiation results comparing this finished model house levels with neighbouring house levels.

4.2.2.4 Ground and Contact Current: After Renovation

Ground current equipment was measured by detecting elevated levels of magnetic fields on the plumbing system. In general, ground current would enter through the home via the plumbing system. A dielectric coupler was installed during construction to avoid current from entering the plumbing system; therefore, the measurements taken indicated that there was no current on the plumbing system.

4.2.2.5 Model House Results Compared to Neighbourhood Houses

Since the model house was not occupied prior to or during construction, low frequency electric and magnetic field measurements taken during construction were not indicative of realistic readings that would otherwise exist in an occupied house when electronics, appliances, and the electrical system are in full operation. Therefore, it was required to take field measurements of a few occupied neighbouring houses to compare the post-renovation results with similar houses that are if full operation. Below are graphs comparing the results of the model house and neighbouring houses.

Dirty Electricity

Figure 4.6a shows a comparison of dirty electricity results. The results clearly show that the installation of 20 GS filters in the model house was effective in reducing dirty electricity to safe levels between 30 and 50 GS units (Refer to Table 3.1 exposure limits); without the GS filters the dirty electricity levels were similar to the other neighbouring houses. The other houses are typical of most residential houses without filters with readings of 150 and above. Even if all the electronics and appliances producing dirty electricity within the house are removed, the GS levels would still be high because it rides along the electrical distribution system from the neighborhood electrical distribution system.

The dirty electricity was the greatest at 21 and 23 Withrow Ave. Both houses had a combination of new and old electrical wiring. One house had higher than normal magnetic fields while the other one did not, but did have higher electric fields. In general, dirty electricity is not associated with the age or configuration of the electrical wiring, or high electric or magnetic fields, as it was observed at 21 and 23 Withrow Ave. It can be attributed to arching on the electrical wiring caused by loose connections. Also, reducing the number of dirty electricity producing electronics and devices did not significantly reduce the dirty electricity levels within the house as we observed at the model house. Dirty electricity is mainly associated with the level entering into the house from the electrical distribution system. However, this requires more monitoring and scientific research to confirm this argument.

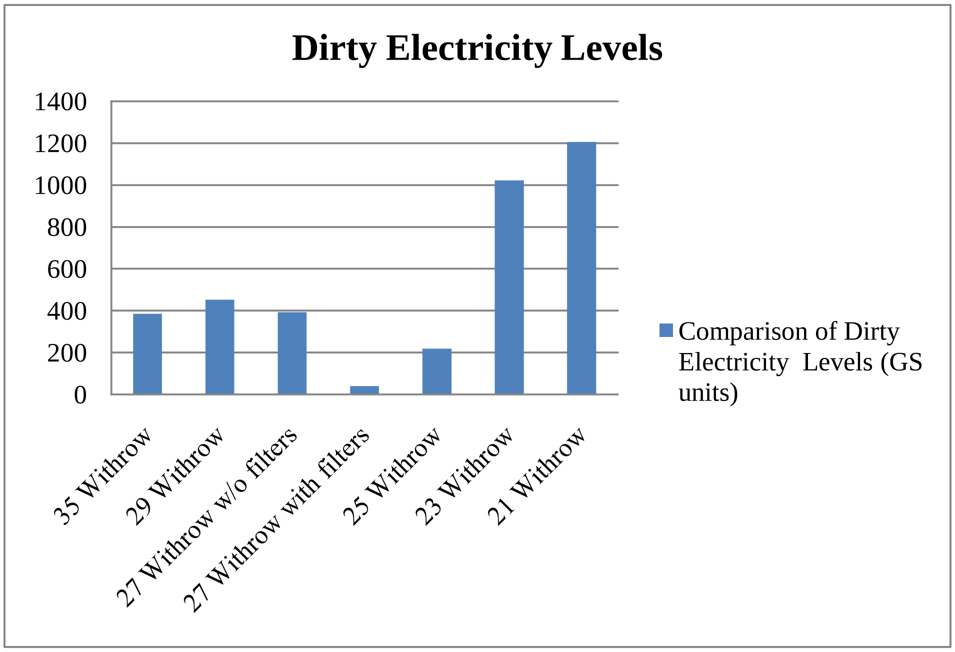

Figure 4.6a: Dirty electricity results of model house compared to neighbouring houses.

AC Electric Fields

Figure 4.6b below shows a comparison of low frequency electric fields; safe levels are considered to be below 1 V/m and of slight concern between 1 and 5 V/m (Refer to Table 3.1 for exposure limits). The results clearly show that the model house has low electric fields due to the shielding effectiveness of using BX armored cable and by reducing the amount of electronics and electrical appliances. Similar results were found at 23 Withrow where there was older wiring but had BX armored cable installed throughout the house. The other homes have higher electric fields throughout the house which is of a slight concern, particularly in the bedrooms, due to unshielded electrical wiring. The installation of demand switches in dedicated rooms to shut off power would be an ideal solution to reduce electric field exposure in the bedrooms during sleep hours. The electric field spot measurements were taken away from appliances and electronics to avoid higher readings.

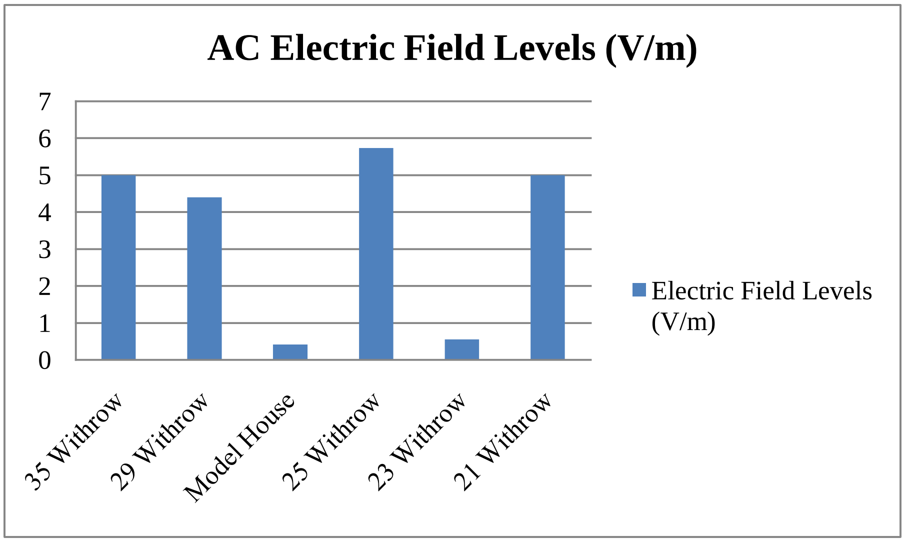

Figure 4.6b: AC electric fields levels of neighboring homes compared to model house.

AC Magnetic Fields

Figure 4.6c shows a comparison of low frequency magnetic fields; safe levels are considered to be below 1 mG and of severe concern between 1 to 5 mG and extreme concern over 5 mG (Refer to Table 3.1 for exposure limits). The results clearly show that the model house has low magnetic fields due to the shielding effectiveness of the opposing copper wire cancelling out the magnetic fields and keeping areas of high magnetic fields away from the living spaces (i.e. electrical panel and electrical service mast), however, there were isolated "hot spots" in the basement, second and third levels. Refer to 4.2.2.2 for further discussion.

The other homes had isolated "hot spots" as well. At 35 Withrow, the east basement wall had elevated levels of magnetic fields as high as 41 mG possibly due to net current or steel frame construction. 29 Withrow had one minor hot spot at an old faulty dimmer switch. 25 Withrow had three isolated hot spots possibly due to faulty wiring causing net current. Higher than normal readings were recorded at 23 Withrow throughout the house between 0.2 and 9.8 mG due to older knob-and-tube wiring; but their newer renovated third floor had low readings below 1 mG. Finally, 21 Withrow had very low magnetic field readings throughout the house; however the electrical panel in the basement, which typically emits high magnetic fields in close proximity, was located adjacent to the TV sofa area which is an extreme concern since it appeared that the room was frequently used by the occupants.

The results indicate the variation in magnetic field levels from house to house and in each case the cause is different. The most probably cause of elevated levels of magnetic fields is due to faulty wiring causing an imbalance of the electrical conductors. In the case of the model house, the steel frame construction, the location of the service panel, and the location of the exterior service mast were the contributing factors causing elevated levels of magnetic fields and will required magnetic field shielding.

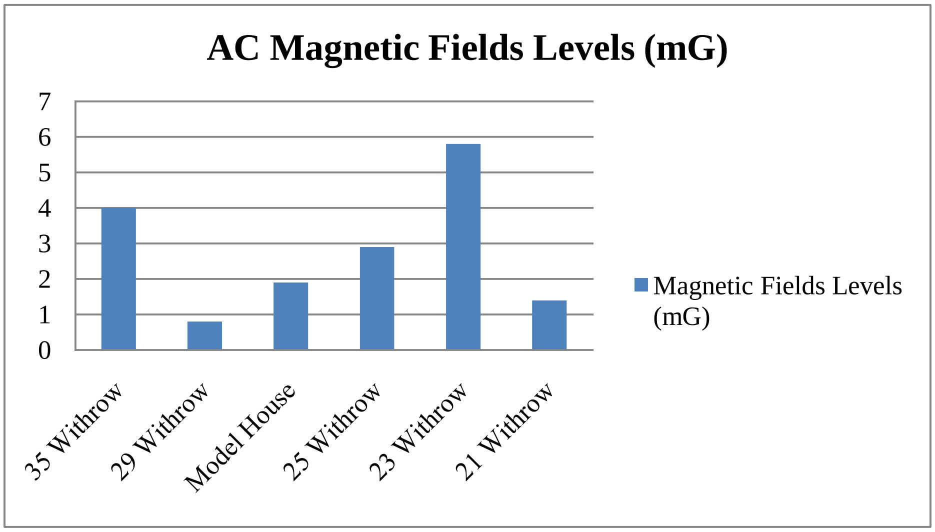

Figure 4.6c: AC magnetic fields levels of neighboring homes compared to model house.

Ground and Contact Current

The model house has a dielectric coupler installed on the municipal water supply, just as it enters the house and after the main electrical ground; therefore, there were no elevated levels of contact current found on the plumbing system. The other homes do not have this part installed and therefore had slightly higher levels of ground current coming in through the plumbing system. The readings were generally below 10 mG which was not a major concern, however, it is recommended to install dielectric couplers as a precautionary measure.

Radio Frequency Radiation

Figure 4.6d shows a comparison of radio frequency radiation levels. In general, most of the homes are constructed similarly with double-wythe (200mm) thick exterior walls and wood framing on the interior. However, the model house has additional spray foam insulation and low-e windows which may have contributed to the very slight reduction of radio frequency radiation transmission through the wall construction. Overall, the results do not show a significant difference between the transmission of radio frequency radiation through the exterior walls when comparing the houses. In general, the level of radio frequency radiation within this area appeared to be low and there were no cell phone antennae's in the area which could contribute to higher neighborhood levels.

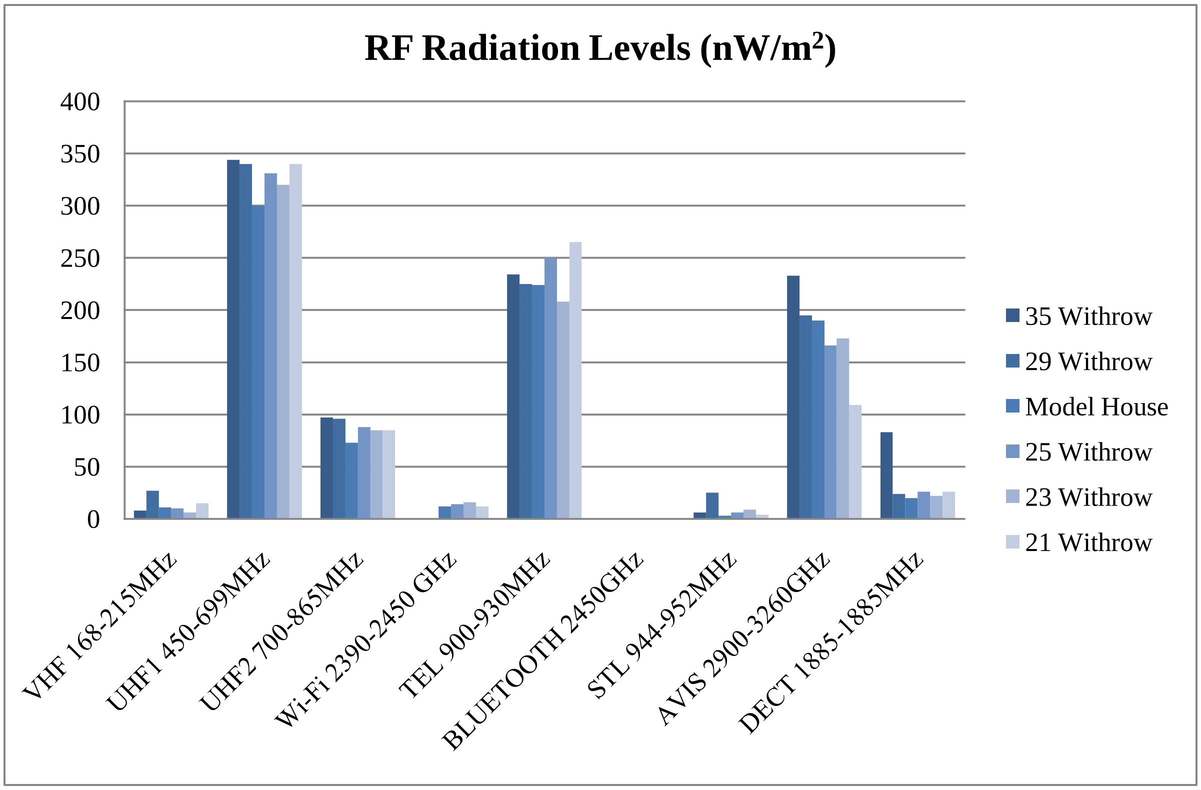

Figure 4.6d: RF radiation levels of neighboring homes compared to model house (nW/m^2).

Power density of high frequency radiation signals is typically measured in W/m^2 (primarily in Europe) or W/cm^2 (primarily in North America). Conversion tables are available in Appendix C. For this project, it is necessary to convert the readings of nW/m^2 to µW/cm^2 to compare results to biological effects listed in Figure 2.13 of this report (100 nW/m^2 = 1 µW/m^2). In general, the results are well below the Health Canada's Safety Code 6. Refer to Table 3.1 and Appendix D for BauBiologie exposure limits.

4.3 Analysis of Results

By comparing the renovated model house to 5 of the neighbouring homes, the performance of the model house could be evaluated. The objective of the model house was to create a healthy, energy-efficient, sustainable house with reduced EMF pollution within the indoor environment as a precautionary measure at either low-cost or no-cost. The results of the questionnaire distributed to each homeowner indicated that all homeowners used wireless communication; used dirty electricity producing electronics and appliances such as compact fluorescent bulbs and high-efficiency washer/dryers; and in general were unfamiliar with EMF pollution. Each house different levels of EMF pollution for a various reasons.

Through this research, the following conclusions can be drawn from the data collected:

1. Significant reduction in AC electric fields was achieved through the use of BX armored cable throughout the model house and one other home, and therefore, the use of demand switches to cut of electrical power in dedicated bedrooms zones was unnecessary. This was a low-cost strategy since some of the cable was reclaimed and the remainder was very low-cost compared to the total cost of the project. Demand switches should otherwise be installed in dedicated bedroom zones where BX armored cable cannot be installed.
2. Significant reduction in AC magnetic fields was achieved through the use of twisted copper conductors in the BX armored cable in the mode house. This was a low-cost strategy since typical conventional electrical wiring was used. However, isolated “hot spots” were recorded at three locations due to attenuation of magnetic fields in the steel frame construction, and proximity to the basement service room, and exterior service mast on the ground and second levels. It has been recommended in this report to avoid the use of steel framed furniture to avoid contact current, and after reviewing the data, it is now also recommended not to use steel frame construction in residential houses as a precautionary measure to avoid magnetic fields due to attenuation. It is also recommended that additional magnetic field shielding is necessary in the basement service room to prevent the spread of magnetic fields in the adjacent rooms in the basement and living room above. It is also recommended that additional magnetic field shielding be installed in the master bedroom where the exterior service mast is located, or, move the bed from that wall to the opposite wall where the magnetic fields are below 1 mG.
3. Significant reduction of dirty electricity to a safe level between 30 and 50 GS was only achieved through the use of 20 GS filters (5 per floor) only. This strategy was a moderate cost that could only be achieved using GS filters. Avoiding the use of dirty electricity producing electronics and devices did not show any reduction of dirty electricity on its own.

4. Very low levels of radio frequency radiation was recorded in all 6 houses possibly due the fact that there are no cell phone or broadcast antennae's in close proximity to the neighbourhood, and due to the fact that all the houses are constructed with two-wythe brick construction which has the ability to absorb a significant amount of radio frequency radiation. In general, the thicker the brick and/or concrete, the more it will absorb at higher frequencies. Even if home owners use wireless communication within their homes, a significant portion will be first absorbed into the brick walls before any is transmitted to the neighbouring houses at which point the remainder will be absorbed into the neighbours brick walls before getting into the house. It can be concluded that older brick homes with thicker wall construction can perform better than single-wythe brick construction in newer homes when it comes to shielding radio frequency radiation. Therefore, restoration of older brick buildings is better than demolishing and building new. Since the parallel goal of this project was to be energy-efficient, the shielding effectiveness of using conductive coated windows was a no-cost strategy. Also, since the exterior brick structure was restored, the shielding effectiveness was also a no-cost strategy; no additional shielding was required.
5. The installation of a dielectric coupler on the plumbing system in the model house eliminated potential ground current from entering the houses plumbing system. It is a low-cost precautionary measure which every house can do.
6. A house with reduced EMF pollution can be achieved through low-cost or no-cost strategies when designing an energy-efficient sustainable house. The installation of the hydronic underfloor heating system eliminated the need for a furnace which in some cases can produce dirty electricity. The uniformity of radiant heat from the floor eliminates the need for using electric heating units and provides a healthier indoor heating system.

In general, the model house did perform better than the other homes due to the lower AC electric and magnetic fields (except for "hot spots" which will have to be addressed), ground and contact current, radio frequency radiation, and dirty electricity. Among the variety of EMF pollutants, electric fields and dirty electricity are now considered more harmful than magnetic fields (Milham and Morgan, 2008); dirty electricity being the greatest EMF pollutant since it is a combination of radio frequency radiation and electricity.

The most profound observation made through this research was that sustainable "green" building choice can assist in reducing EMF pollution and at the same time be beneficial for the environment by reducing energy consumption within the building.

5 Conclusion

The world today could not exist without electricity since its primary function is to power our buildings and everything in them including lights, computers, and just about anything with a plug. It is also used as a source of heating buildings. The demand for electricity has increased since the industrial revolution which has caused a negative environmental impact through depletion of our natural resources and accelerated the rate of global warming through toxic emissions into the earth's atmosphere. As the demand for electricity increases, there is also a parallel demand for wireless communication. Electricity produces both low frequency electric and magnetic fields (EMFs) and wireless communication produces radio frequency radiation (EMR). Both electricity and wireless communication devices produce EMF and EMR which scientists have identified as an indoor environmental pollutant or toxin that has ubiquitously plagued developed nations causing a variety of adverse health effects such as sick-building syndrome symptoms, asthma, diabetes, multiple sclerosis, leukemia, electro-hypersensitivity (EHS), behavior disorders, and more (Firstenberg, 2001; Havas, 2007).

In 2002, the International Agency of Research on Cancer (IARC), a division of World Health Organization, classified electromagnetic pollution as a "possible carcinogen". Based on thousands of epidemiological and laboratory studies, many international governments and organizations have adopted the *prudent avoidance principal* or *precautionary principal* until a firm scientific link between EMF and disease is established. The policy of prudent avoidance is a precautionary principal to reduce potential risk to the general public through reasonable efforts and can vary among countries, governments, and local authorities as to the extent of action to be taken. In Canada, there are no standard EMF exposure limits for everyday home or office electronics and appliances; however, Safety Code 6 produced at the federal government level provides exposure limits for radiowaves. In 2008, the Greater Toronto Authority (GTA) adopted the policy of prudent avoidance to reduce childhood exposure to EMF in and adjacent to hydro corridors only.

Scientific studies have suggested that the increased demand for electricity and wireless communication is a global phenomena causing harm not only to the environment but also to health. Unfortunately, there is currently no international consensus on guidelines and exposure limits. Sweden, home of the World Health Organization building, has taken the lead on precautionary measures and enforces the strictest exposure limits in the world. Countries like the UK, USA, and Canada are the furthest behind in setting exposure standards and guidelines until the scientists find the link or mechanism which can cause disease from exposure to EMF or EMR.

Thus, the objective of this research was to extend the prudent avoidance principal into residential construction by developing and implementing design strategies to reduce EMF pollution through low-cost or no-cost measures. The design strategies were implemented in the renovation of a1909, three-storey, single family dwelling, as part of Renovation 2050 – a sustainable renovation initiative located in Toronto, Ontario. From this research, it was found that any renovation or new construction intending to have reduced EMF and EMR exposure would require an integrated design approach in developing a sustainable, energy-efficient house, while creating a high quality, healthy, indoor environment. Results indicate that careful design and selection of building envelope materials, lighting, HVAC system, electrical wiring and configuration, floor plan, and passive solar design strategies not only reduce energy consumption but also significantly reduce exposure to EMF pollution.

A renovation intended to be sustainable and energy-efficient may actually produce more EMF pollution within the indoor environment by selecting the wrong electronics and devices, and the design may not even consider other methods of building systems other than conventional methods due to cost (i.e. conventional Romex electrical wiring vs. BX armored cable). On the other hand, a renovation intended to have reduced EMF and EMR pollution may not be as energy-efficient (i.e. using incandescent instead of LED's), and precautionary measures may be limited due to high cost (i.e. hydronic underfloor heating system vs. conventional furnace). For example, in this project, the installation of a gas boiler used to heat the water in the home as well as to supply heated water to the hydronic underfloor heating system that was installed throughout the house on all floors, was not only the most energy-efficient and healthiest way to heat a home, but it also produced no EMF pollution; thus, the high cost for this installation in a sustainable and energy-efficient renovation was actually no cost in creating an environment with no EMF pollution. It was also found from this research that building materials such as brick and concrete provide the greatest resistance to EMR transmission; the thicker the material the greater the absorption. Therefore, renovation of older brick buildings is a better option rather than demolishing and building new construction.

From this research, it was found that EMF and EMR can potentially cause disease and illnesses. By strategically removing indoor environmental pollutants and/or stresses can drastically improve health of those suffering from illness such as multiple sclerosis, diabetes, headaches, fatigue, electrohypersensitivity, and more (Havas, 2007). Any renovation or new construction can apply the strategies used in this project, at a very moderate cost, to create an indoor environment that has reduced EMF and EMR pollution.

In this report, the level of action required to reduce EMF and EMR pollution, was defined by priorities: priority 1 being action taken by homeowners at a low cost; priority 2 was being action taken by the homeowner and contractor at a moderate cost; and priority 3 was being action take during a major renovation or new construction. The parallel goals of this research were to be sustainable, energy-efficient, and healthy. This was only achieved through an integrated design process.

Through this research it was also found that "green" building choices can assist in reducing EMR transmission into the building by using green building systems such as a green roof and low-e conductive coating on windows. The benefit of installing green building systems not only reduces EMR but is also beneficial for the environment (i.e. reducing heat island effect with a green roof). Due to the low EMR levels recorded, it was not necessary to install a green roof system. Conventional brick and concrete also provide excellent EMR absorption; therefore, restoration of older buildings would be better and more sustainable option rather than demolishing and building new construction. Also, through this research it was found that it would be better to use traditional wood frame construction throughout the house as a precautionary measure to avoid attenuation of magnetic fields through steel stud construction. Not only is wood more sustainable than steel, but it is also non-conductive to electric and magnetic fields. In general, avoiding metal furniture and objects within the home is a precautionary measure that will prevent ground and contact current from occurring. Overall, the renovation was a success in reducing EMF pollution within the indoor environment and achieving a sustainable renovation.

Future Research

One area of research which should be further pursued is the association between dirty electricity and electrical wiring types and configuration. From this research, it appeared that there are no associations; however, further research would be required to confirm these conclusions. Another area of research is on magnetic field behavior with steel stud construction and cables as well as the art of magnetic field shielding.

One of the most important questions which arose from this research was how radio frequency radiation emitted from wireless communication devices and antennae's affects global warming. If this type of energy can heat the tissue within the body, how would it affect the greenhouse gasses trapped in the atmosphere? It may be a significant contributing factor to the current environmental crisis today. This is a critical area of research which should be addressed.

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Helpful Links to Related EMF Pollution

- Ontario Energy Board (OEB) – www.oeb.gov.on.ca
- Ontario Power Authority (OPA) – www.powerauthority.on.ca
- Electrical Safety Authority (ESA) – www.esasafe.com
- Independent Electrical System Operator (IESO) – www.ieso.ca
- The Ontario Ministry of Energy, Science and Technology (MEST) – www.energy.gov.on.ca
- Ministry of Energy – www.energy.gov.on.ca
- The Electricity Distributors Association (EDA) www.eda-on.ca
- The Office of Energy Efficiency (OEE), Natural Resources Canada – http://oee.nrcan.gc.ca
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Appendix A: Photographs

Photo 1: North elevation of 27 Withrow Avenue, Toronto, Ontario.

Photo 2: Electrical service mast at third floor; moved to second floor creating a localized “hot spot”.

Photo 3: Steel stud framing in the basement.

Photo 4: Dielectric coupler installed on plumbing system.

Photo 5: BX armored cable installed throughout the house.

Photo 6: Copper plumbing for hydronic underfloor heating system.

Appendix B: Summary of Construction Costs

EMF POLLUTANT	SOURCE	MITIGATION STRATEGY	MATERIAL SPECIFICATION	COST
Electric Fields	clock radios, laptops, lamps, electrical wires with current	Without shielding keep 10-15 ft. distance away from source. Use BX steel cable to eliminate electric fields from wiring. Ground neutral to earth and not plumbing. Use a separate circuit for dryer, fridge, computers, bedrooms	 BX steel cable grounding plate	 $75/roll Low-cost No add. cost
Magnetic Fields	above and below ground power lines, hydro towers, transformers, computers, low-voltage lighting, homes electrical mast and panel, faulty or outdated wiring	Without shielding keep 4 ft. distance away from source. Use standard Romex wiring which contains the live, neutral, and copper in one cable. Use Mumetal in electrical room and at electrical feed.	 Romex wiring Mumetal sheets	 No add. cost $20/sq.ft.
Plumbing Current	electrical current on water pipe	Install a dielectric coupler, or insulating coupling, in the water supply line to the building.	di-electric coupler	$30
Ground Current	Earth Current refers to the flow of primary return current (multi-grounded-neutrals) through the earth back to the serving substation	Not applicable – problem with dairy farmers.		$0
Radio Frequency	DECT cordless phones, baby monitors, cell phone towers, Wi-Fi networks, satellite TV, radars, and dirty electricity	Use low-e windows. Use conductive canopies around beds if there are RFs. Use conduct fabric or paint at locations where there is RF. Use green roof only if RF is present (i.e. cell phone tower).	low-e windows	No add. cost High-cost High-cost High-cost
Dirty Electricity	CFL's, ballasts and transformers, dimmer switches, low-voltage halogen, fluorescent tubes, energy-efficient devices, some variable-speed drives in furnaces, fans, heaters, front loading washing machines, treadmills, blenders/mixers, electrical outlet and wires	Get each of the home's circuits meter readings down to below 50 GS - install one per circuit and two at the electrical panel. Use GS power-bar which has two filters installed. Use incandescent or LEDs.	approx. 20 GS filters and one microsurge meter GS power-bar entertainment and computer. low-watt incandescent, or low-watt LEDs	$975 $114 each Low-cost High-cost

The following lists some additional considerations in reducing electromagnetic pollution within your environment:

	Source	Mitigation Strategy	Material Specification	Cost
Electric and Magnetic Fields	stove	Use gas stove instead of electric.	gas stove	No add. Cost
	clothes dryer	Consider air drying.	clothes line	Low-cost
	hair dryer	Use one with 4 ft. hose that is wall mounted.	wall mounted hair dryer	$90 US each
	lawn mower	Use non-electric lawn mower.	non-electric lawn mower	Low-cost
	front load washing machines	Use traditional top loading machines	top load wash machine	Low-cost
	door bell	Use wireless doorbell to avoid additional wiring.	mechanical door bell	Low-cost
Dirty Electricity	artificial lighting	Use passive solar design strategies – install skylights above stairwell.	skylights	Low-cost
		Install demand switches in each bedroom to shut off power during the night to reduce exposure, also	demand switches	$250 each
		Install one circuit per bedroom for the demand switch upgrade.	one circuit per bedroom	Low-cost
Radio Frequency	DECT wireless telephones	Use traditional landline phones.	landline phones	Low-cost
	wireless Internet	Avoid all indoor wireless devices.	cable internet	Low-cost
HVAC	electric heating	Avoid electrical baseboards and heaters.	hydronic under-floor heating system	High-cost
	air conditioner	Only use if necessary. Keep away from common rooms.		

Appendix C: Conversion Tables and Terms

Table 1 Conversion from W/m² to µW/cm² and mW/cm²

0.000,001 W/m²	0.000,1 µW/cm²	0.000,000,1 mW/cm²
0.000,01 W/m²	0.001 µW/cm²	0.000,001 mW/cm²
0.000,1 W/m²	0.01 µW/cm²	0.000,01 mW/cm²
0.001 W/m²	0.1 µW/cm²	0.000,1 mW/cm²
0.01 W/m²	1 µW/cm²	0.001 mW/cm²
0.1 W/m²	10 µW/cm²	0.01 mW/cm²
1 W/m²	100 µW/cm²	0.1 mW/cm²

Table 2 Conversion from µW/cm² to V/m and A/m

0.000,1 µW/cm²	0.019,4 V/m	0.000,051,5 A/m
0.001 µW/cm²	0.061,4 V/m	0.000,162 A/m
0.01 µW/cm²	0.194 V/m	0.000,515 A/m
0.1 µW/cm²	0.614 V/m	0.001,62 A/m
1 µW/cm²	1.94 V/m	0.005,15 A/m
10 µW/cm²	6.14 V/m	0.016,2 A/m
100 µW/cm²	19.4 V/m	0.051,5 A/m

Table 3 dBm to dBW and W (incl. respective fractional units):

0 dBm	-30dBW	0.001W	1mW
-10dBm	-40dBW	0.000,1W	100µW
-20dBm	-50dBW	0.000,01W	10µW
-30dBm	-60dBW	0.000,001W	1µW
-40dBm	-70dBW	0.000,000,1W	100nW
-50dBm	-80dBW	0.000,000,01W	10nW
-60dBm	-90dBW	0.000,000,001W	1nW
-70dBm	-100dBW	0.000,000,000,1W	100pW

dBm = Decibelmilliwatts, dBW = DecibelWatts, W = Watts,
mW = MilliWatts, µW=MicroWatts, nW= NanoWatts, pW=PicoWatts

Table 4 Frequency, wavelength and frequency band denomination

3 Hz-30 Hz	100,000 km - 10,000 km	ULF
30 Hz-300 Hz	10,000 km - 1,000 km	ELF
300 Hz-3 kHz	1,000 km - 100 km	VF
3 kHz-30 kHz	100 km - 10 km	VLF
30 kHz-300 kHz	10 km - 1 km	LF
300 kHz-3 MHz	1 km - 100 m	MF
3 MHz-30 MHz	100 m - 10 m	HF
30 MHz-300 MHz	10 m - 1 m	VHF
300 MHz-3 GHz	1 m - 10 cm	UHF
3 GHz - 30 GHz	10 cm - 1 cm	SHF

m = 1/1000 (one thousandth)
µ = 1/1,000,000 (one millionth)
n = 1/1,000,000,000 (one billionth)
p = 1/1,000,000,000,000 (one trillionth)
f = 1/1,000,000,000,000,000 (one quadrillionth)

The decibel is widely used to describe radio frequency (RF) when measuring RF or power. As a result, many power levels are specified in dBm or dBW, and many RF test equipment including power meters and spectrum analysers displace measurements in dB and power density. In itself, a decibel is no tan absolute level. It is purely a comparison between two levels, and on its own cannot be used an absolute level. The dBm is a power expressed in decibels relative to one milliwatt of power. The dBW is a power expressed in decibels relative to one watt of power. Table 4 below is conversion table of dBm, dBW and power.

Table 4: Conversion table of dBm, dBW, and Power

DBM	DBW	WATTS	TERMINOLOGY
+100	+70	10 000 000	10 Megawatts
+90	+60	1 000 000	1 Megawatt
+80	+50	100 000	100 kilowatts
+70	+40	10 000	10 kilowatts
+60	+30	1 000	1 kilowatt
+50	+20	100	100 watts
+40	+10	10	10 watts
+30	0	1	1 watt
+20	-10	0.1	100 milliwatts
+10	-20	0.01	10 milliwatts
0	-30	0.001	1 milliwatt
-10	-40	0.0001	100 microwatts
-20	-50	0.00001	10 microwatts
-30	-60	0.000001	1 microwatt
-40	-70	0.0000001	100 nanowatts
-50	-80	0.00000001	10 nanowatts
-60	-90	0.000000001	1 nanowatts

IEEE Standard Radar Band Nomenclature (*IEEE Std. 521-2002, IEEE Standard Letter Designations for Radar-Frequency Bands)		
Designation	**Frequency**	**Wavelength**
HF	3 - 30 MHz	100 m - 10 m
VHF	30 - 300 MHz	10 m - 1 m
UHF	300 - 1000 MHz	100 cm - 30 cm
L Band	1 - 2 GHz	30 cm - 15 cm
S Band	2 - 4 GHz	15 cm - 7.5 cm
C Band	4 - 8 GHz	7.5 cm - 3.75 cm
X Band	8 - 12 GHz	3.75 cm - 2.50 cm
Ku Band	12 - 18 GHz	2.50 cm - 1.67 cm
K Band	18 - 27 GHz	1.67 cm - 1.11 cm
Ka Band	27 - 40 GHz	1.11 cm - .75 cm
V Band	40 - 75 GHz	7.5 mm - 4.0 mm
W Band	75 - 110 GHz	4.0 mm - 2.7 mm
mm Band	110 - 300 GHz	2.7 mm - 1.0 mm

International Telecommunications Union (ITU) Radar Band Nomenclature (ITU classifications are based on region-2 radiolocation service allocations)	
Band Designation	**Frequency**
VHF	138 - 144 MHz 216 - 225 MHz
UHF	420 - 450 MHz 890 - 942 MHz
L	1.215 - 1.400 GHz
S	2.3 - 2.5 GHz 2.7 - 3.7 GHz
C	5.250 - 5.925 GHz
X	8.500 - 10.680 GHz
Ku	13.4 - 14.0 GHz 15.7 - 17.7 GHz
K	24.05 - 24.25 GHz 24.65 - 24.75 GHz
Ka	33.4 - 36.0 GHz
V	59.0 - 64.0 GHz
W	76.0 - 81.0 GHz 92.0 - 100.0 GHz
mm	126.0 - 142.0 GHz 144.0 - 149.0 GHz 231.0 - 235.0 GHz 238.0 - 248.0 GHz

Military Radar Band Designations		
Band	**Frequency**	**Wavelength**
HF	3 - 30 MHz	100 m - 10 m
VHF	30 - 300 MHz	10 m - 1 m
UHF	300 - 1000 MHz	100 cm - 30 cm
L	1 - 2 GHz	30 cm - 15 cm
S	2 - 4 GHz	15 cm - 7.5 cm
C	4 - 8 GHz	7.5 cm - 3.75 cm
X	8 - 12 GHz	3.75 cm - 2.50 cm
Ku	12 - 18 GHz	2.50 cm - 1.67 cm
K	18 - 27 GHz	1.67 cm - 1.11 cm
Ka	27 - 40 GHz	1.11 cm - .75 cm
mm	40 - 300 GHz	7.5 mm - 1.0 mm

ITU Frequency Band Nomenclature			
ITU Band	**Designation**	**Frequency**	**Wavelength**
1	ELF	3 - 30 Hz	100,000 km - 10,000 km
2	SLF	30 - 300 Hz	10,000 km - 1000 km
3	ULF	300 - 3000 Hz	1000 km - 100 km
4	VLF	3 - 30 kHz	100 km - 10 km
5	LF	30 - 300 kHz	10 km - 1 km
6	MF	300 - 3000 kHz	1 km - 100 m
7	HF	3 - 30 MHz	100 m - 10 m
8	VHF	30 - 300 MHz	10 m - 1 m
9	UHF	300 - 3000 MHz	1 m - 10 cm
10	SHF	3 - 30 GHz	10 cm - 1 cm
11	EHF	30 - 300 GHz	1 cm - 1 mm

Band Designation Acronyms
Extremely Low Frequency (ELF) Super Low Frequency (SLF) Ultra Low Frequency (ULF) Very Low Frequency (VLF) Low Frequency (LF) Medium Frequency (MF) High Frequency (HF) Very High Frequency (VHF) Ultra High frequency (UHF) Super High Frequency (SHF) Extremely High Frequency (EHF)

Appendix D: Bau-Biologie Exposure Limits

Building Biology Evaluation Guidelines for Sleeping Areas SBM-2008, Page 1		No Concern	Slight Concern	Severe Concern	Extreme Concern

A FIELDS, WAVES, RADIATION

1 AC ELECTRIC FIELDS (Low Frequency, ELF/VLF)

		No Concern	Slight Concern	Severe Concern	Extreme Concern
Field strength with ground potential in volt per meter	V/m	< 1	1 - 5	5 - 50	> 50
Body voltage with ground potential in millivolt	mV	< 10	10 - 100	100 - 1000	> 1000
Field strength potential-free in volt per meter	V/m	< 0.3	0.3 - 1.5	1.5 - 10	> 10

Values apply up to and around 50 (60) Hz, higher frequencies and predominant harmonics should be assessed more critically.

ACGIH occupational TLV: 25 000 V/m; DIN/VDE: occupational 20 000 V/m, general 7000 V/m; ICNIRP: 5000 V/m; TCO: 10 V/m; US-Congress/EPA: 10 V/m; BUND: 0.5 V/m; studies on oxidative stress, free radicals, melatonin, childhood leukaemia: 10-20 V/m; nature: < 0.0001 V/m

2 AC MAGNETIC FIELDS (Low Frequency, ELF/VLF)

		No Concern	Slight Concern	Severe Concern	Extreme Concern
Flux density in nanotesla	nT	< 20	20 - 100	100 - 500	> 500
in milligauss	mG	< 0.2	0.2 - 1	1 - 5	> 5

Values apply to frequencies up to and around 50 (60) Hz, higher frequencies and predominant harmonics should be assessed more critically. Line current (50-60 Hz) and traction current (16.7 Hz) are recorded separately.

In the case of intense and frequent temporal fluctuations of the magnetic field, data logging needs to be carried out - especially during nighttime - and for the assessment, the 95th percentile is used.

DIN/VDE: occupational 5 000 000 nT, general 400 000 nT; ACGIH occupational TLV: 200 000 nT; ICNIRP: 100 000 nT; Switzerland 1000 nT; WHO: 300-400 nT "possibly carcinogenic"; TCO: 200 nT; US-Congress/EPA: 200 nT; BioInitiative: 100 nT; BUND: 10 nT; nature: < 0.0002 nT

3 RADIOFREQUENCY RADIATION (High Frequency, Electromagnetic Waves)

		No Concern	Slight Concern	Severe Concern	Extreme Concern
Power density in microwatt per square meter	$\mu W/m^2$	< 0.1	0.1 - 10	10 - 1000	> 1000

Values apply to single RF sources, e.g. GSM, UMTS, WiMAX, TETRA, Radio, Television, DECT cordless phone technology, WLAN..., and refer to peak measurements. They do not apply to radar signals.

More critical RF sources like pulsed or periodic signals (mobile phone technology, DECT, WLAN, digital broadcasting...) should be assessed more seriously, especially in the higher ranges, and less critical RF sources like non-pulsed and non-periodic signals (FM, short, medium, long wave, analog broadcasting...) should be assessed more generously especially in the lower ranges.

Former Building Biology Evaluation Guidelines for RF radiation / HF electromagnetic waves (SBM-2003): pulsed < 0.1 no, 0.1-5 slight, 5-100 strong, > 100 $\mu W/m^2$ extreme anomaly; non-pulsed < 1 no, 1-50 slight, 50-1000 strong, > 1000 $\mu W/m^2$ extreme anomaly

DIN/VDE: occupational up to 100000000 $\mu W/m^2$, general up to 10000000 $\mu W/m^2$; ICNIRP: up to 10000000 $\mu W/m^2$; Salzburg Resolution / Vienna Medical Association: 1000 $\mu W/m^2$; BioInitiative: 1000 $\mu W/m^2$ outdoor; EU-Parliament STOA: 100 $\mu W/m^2$; Salzburg: 10 $\mu W/m^2$ outdoor, 1 $\mu W/m^2$ indoor; EEG / immune effects: 1000 $\mu W/m^2$; sensitivity threshold of mobile phones: < 0.001 $\mu W/m^2$; nature < 0.000001 $\mu W/m^2$

4 DC ELECTRIC FIELDS (Electrostatics)

		No Concern	Slight Concern	Severe Concern	Extreme Concern
Surface potential in volt	V	< 100	100 - 500	500 - 2000	> 2000
Discharge time in seconds	s	< 10	10 - 30	30 - 60	> 60

Values apply to prominent materials and appliances close to the body and/or to dominating surfaces at ca. 50 % r.h.

TCO: 500 V; damage of electronic parts: from 100 V; painful shocks and actual sparks: from 2000-3000 V; synthetic materials, plastic finishes: up to 10 000 V; synthetic flooring, laminate: up to 20 000 V; TV screens: up to 30 000 V; nature: < 100 V

5 DC MAGNETIC FIELDS (Magnetostatics)

		No Concern	Slight Concern	Severe Concern	Extreme Concern
Deviation of flux density (steel) in microtesla	μT	< 1	1 - 5	5 - 20	> 20
Fluctuation of flux density (current) in microtesla	μT	< 1	1 - 2	2 - 10	> 10
Deviation of compass needle in degree	°	< 2	2 - 10	10 - 100	> 100

Values for the deviation of the flux density in μT apply to metal/steel and for the fluctuation of the flux density to direct current.

DIN/VDE: occupational 67 900 μT, general 21 200 μT; USA/Austria: 5000-200 000 μT; MRI: 2-4 T; earth's magnetic field: across temperate latitudes 40-50 μT, equator 25 μT, north/south pole 65 μT; eye: 0.0001 nT, brain: 0.001 nT, heart: 0.05 nT; animal navigation: 1 nT; 1 μT = 10 mG

6 RADIOACTIVITY (Gamma Radiation, Radon)

		No Concern	Slight Concern	Severe Concern	Extreme Concern
Equivalent dose rate increase in percent	%	< 50	50 - 70	70 - 100	> 100

Values apply in relation to local background levels: Germany on average 0.8 mSv/a (100 nSv/h). At substantial deviations from this mean background radiation, the reference ranges for the equivalent dose rate increase need to be decreased accordingly.

Radiation Protection Germany: general 1 mSv/a additional exposure, workers 20 mSv/a; BGA: general 1.67 mSv/a; USA federal law: general 5 mSv/a, workers 50 mSv/a; Germany background: < 0.6 mSv/a (< 70 nSv/h) north, > 1.4 mSv/a (> 165 nSv/h) south, Black Forest, Bavaria

		No Concern	Slight Concern	Severe Concern	Extreme Concern
Radon in becquerel per cubic meter	Bq/m^3	< 30	30 - 60	60 - 200	> 200

EU: 400 Bq/m^3 (old buildings), 200 Bq/m^3 (new buildings); Radiation Protection Germany: 250 Bq/m^3; Sweden, Canada: 200 Bq/m^3; US EPA: 150 Bq/m^3; England: 100 Bq/m^3 (new buildings); WHO: 100 Bq/m^3; German Radon Protection Act (draft): 100 Bq/m^3; avg. indoor levels: 20-50 Bq/m^3, avg. outdoor levels: 5-15 Bq/m^3; radon mine: 100 000 Bq/m^3; lung cancer risk increase by 10% for each 100 Bq/m^3; Bq/m^3 x 0.027 = pCi/l

7 GEOLOGICAL DISTURBANCES (Geomagnetic Field, Terrestrial Radiation)

		No Concern	Slight Concern	Severe Concern	Extreme Concern
Disturbance of geomagnetic field in nanotesla	nT	< 100	100 - 200	200 - 1000	> 1000
Disturbance of terrestrial radiation in percent	%	< 10	10 - 20	20 - 50	> 50

Values apply in relation to the natural geomagnetic field and the earth's natural background of gamma or neutron radiation.

Natural fluctuation of the earth magnetic field: temporal 10-100 nT; magnetic storms / solar eruptions: 100-1000 nT; decrease per year: 20 nT

Appendix E: Sample of Questionnaire

November 5, 2010

Dear Neighbour,

This letter is a request for your permission to volunteer in a graduate research study with the Department of Architectural Science, Ryerson University. The research is being conducted by graduate student, Yasmeen Siddiqui, MBSci. Candidate, under the direct supervision of faculty advisor, Dr. Russell Richman, P.Eng. The research study is entitled “Innovative Design Strategies to Reduce Electromagnetic Pollution from the Indoor Environment”.

The renovation at 27 Withrow Ave. has been completed by your neighbor, Dr. Russell Richman, which has been designed to reduce electromagnetic field (EMF) pollution emissions which originate from a variety of EMF sources within the indoor and outdoor environment such as electrical wiring, wireless communication devices, and energy-efficient devices and appliances. We have been continuously monitoring the EMF levels during construction and need to compare our results with EMF levels with two neighbouring homes on both sides of 27 Withrow Ave. The goal of this renovation is to achieve a healthy indoor environment with a significant reduction of EMF.

Attached is a detailed description of our research and a consent form for you to sign if you agree to volunteer. We would simply like to conduct a quick 30-minute EMF spot survey of your home and we are also requesting for you to compete a short questionnaire. If you have any questions, please contact the undersigned.

Sincerely,

Yasmeen Siddiqui, Graduate Student,
Department of Architectural Science, Ryerson University
(416) 919-1978, or

Dr. Russell Richman, Faculty Staff
Department of Architectural Science, Ryerson University
(416) 979-5000 Ext.6489

Department of Architectural Science, Ryerson University
Consent Agreement

"Innovated Design Strategies to Reduce Electromagnetic Pollution from the Indoor Environment"

You are being asked to participate in a graduate research study with the Department of Architectural Science, Ryerson University. It will involve a brief four-page questionnaire and a 30 minute site review of your home. The results of the questionnaire and site survey will assist us in our analysis of 27 Withrow Ave.

Before you give your consent to be a volunteer, it is important that you read the following information and ask as many questions as necessary to be sure you understand what you will be asked to do.

Investigators: The research study is being conducted by graduate student, Yasmeen Siddiqui, MBSc. Candidate, under the supervision of faculty staff, Professor Russell Richman, who is also the owner and occupant of 27 Withrow Ave.

Purpose of the Study:

The research study is entitled "Innovative Design Strategies to Reduce Electromagnetic Pollution from the Indoor Environment".

The renovation at 27 Withrow Ave. is almost complete and has been designed to reduce electromagnetic pollution emissions which originate from a variety of electromagnetic field (EMF) sources within the indoor and outdoor environment such as electrical wiring, wireless communication devices, and energy-efficient devices and appliances. We have been continuously monitoring the EMF levels during construction and need to compare our results with EMF levels with two neighbouring homes on both sides of 27 Withrow Ave. The goal of this renovation is to achieve a healthy indoor environment with a significant reduction of EMF.

Description of the Study:

We require the completion of a brief four-page questionnaire. We will also require access to your home to take spot EMF measurements (i.e. electrical panel, basement, ground floor kitchen, living, dining, bedrooms, backyard, and front yard). The site survey will not take more than 30 minutes of your time. The data collected will provide us with background EMF readings during regular occupancy as a reference which we were unable to collect at 27 Withrow Ave. since construction commenced prior to occupancy.

What is Experimental in this Study:

The purpose of this research study is to gather information for analysis. For the site survey, we will be using a small, hand-held, EMF detector to measure electric and magnetic fields within your home. The main sources of EMF come from electrical wiring and appliances. We will take spot measurements inside and outside the home with all lights turned off and then with all lights turned on. This will tell us if there are any elevated EMF fields generating from within the home.

Risks or Discomforts: We will require approximately 30 minutes in your home for our site survey which we may be discomforting for any occupants in the house.

Benefits of the Study: This research study will provide the scientific community and those in the construction industry with valuable information on how to develop an indoor environment with a significant reduction in EMF which can be very beneficial to better quality of life, health, and well-being.

Confidentiality: The names of the building occupants and personal information are not required.

Incentives to Participate: As a home owner, you may be interested in knowing your EMF level in your indoor environment at now cost to you.

Costs and/or Compensation for Participation: There is no cost and/or compensation for participation.

Voluntary Nature of Participation: Participation in this study is voluntary. If you decide to participate, you are free to withdraw your consent and to stop your participation at any time.

At any particular point in the study, you may refuse to answer any particular question or stop participation altogether.

Questions about the Study: If you have any questions about the research now, please ask. If you have questions later about the research, you may contact:

Yasmeen Siddiqui, Graduate Student,
Department of Architectural Science, Ryerson University
(416) 919-1978, or

Dr. Russell Richman, Faculty Staff
Department of Architectural Science, Ryerson University
(416) 979-5000 Ext.6489

If you have questions regarding your rights as a participant in this study, you may contact the Ryerson University Research Ethics Board for information:

Research Ethics Board
c/o Office of the Vice President, Research and Innovation
Ryerson University
350 Victoria Street, Toronto, ON, M5B 2K3
416-979-5042

AGREEMENT:

Your signature below indicates that you have read the information in this agreement and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to be in the study and have been told that you can change your mind and withdraw your consent to participate at any time. You have been given a copy of this agreement.

You have been told that by signing this consent agreement you are not giving up any of your legal rights.

____

Name of Participant (please print)

_______________________________________ ___________________

Signature of Participant Date

_______________________________________ ___________________

Signature of Investigator Date

QUESTIONNAIRE: **Page 1 of 4**

The following is a questionnaire for the participants of a research study being conducted by graduate student, Yasmeen Siddiqui, MBSc. Candidate, under the supervision of faculty staff, Professor Russell Richman, Department of Architectural Science, Ryerson University. The title of the study is, 'Innovative Design Strategies to Reduce Electromagnetic Pollution from the Indoor Environment'.

The questionnaire should take no more than 10-15 minutes of your time. Please place a check-mark in the appropriate box. Additional space to the right is provided for any comments.

Thank you for your participation.

HEATING SYSTEM:

What type of heating system do you currently have in your home?

- forced-gas furnace ☐
- radiators ☐
- electrical base boards ☐
- electric under-floor heating ☐
- water-tubes under-floor heating ☐
- gas fireplace ☐
- electric fireplace ☐
- other ☐

ELECTRICAL SYSTEM:

What type of electrical system do you currently have in your home?

- old knob & tube ☐
- upgraded Romex ☐

What is the amperage of your electrical system?

- 100 Amps. ☐
- 200 Amps. ☐
- other ☐

Do you have solar power panels installed?

- yes ☐
- no ☐

Are you aware of any electrical grounding or wiring errors?

- yes ☐
- no ☐

If yes, please describe.

APPLIANCES:

What type of appliances do you have?

gas range	☐	__________
electric range	☐	__________
fridge	☐	__________
wall ovens	☐	__________
dishwasher	☐	__________
high-efficiency washer	☐	__________
non-efficiency washer	☐	__________
high-efficiency dryer	☐	__________
non-efficiency dryer	☐	__________
other	☐	__________

COMPUTERS & ELECTRONICS:

Please indicate the type of computer and/or electronics you use in your home.

desktop computer	☐	__________
laptop computer	☐	__________
TV	☐	__________
clock radio	☐	__________
hair dryer	☐	__________
treadmill	☐	__________
lamps	☐	__________
small kitchen appliances	☐	__________
other	☐	__________

WIRELESS DEVICES:

Please indicate the type of wireless devices in your home.

baby monitor	☐	__________
cordless phones	☐	__________
cell phones	☐	__________
blackberry	☐	__________
Bluetooth	☐	__________
satellite dish	☐	__________
AM/FM Radio	☐	__________
wireless internet	☐	__________

LIGHTING:

Please indicate the type of light bulbs you use.

compact fluorescent bulbs (CFL's) ☐ ____________________
incandescent ☐ ____________________
LED's ☐ ____________________
tubular fluorescent ☐ ____________________
halogen ☐ ____________________
other ☐ ____________________

Do you have pot lights?

yes ☐ ____________________
no ☐ ____________________

Do you have dimmer switches?

yes ☐ ____________________
no ☐ ____________________

FURNITURE:

Indicate the type of bed that you and other occupants sleep on.

box spring and mattress ☐ ____________________
only mattress ☐ ____________________
futon ☐ ____________________
air mattress ☐ ____________________
other ☐ ____________________

Indicate the type of bed frames used for you and other occupants.

metal frame ☐ ____________________
wood frame ☐ ____________________
plastic frame ☐ ____________________
other ☐ ____________________

WINDOWS:

Indicate the type of windows you have in your home.

operable windows with low-e coating	☐	____________
fixed windows with low-e coating	☐	____________
windows with no low-e coating	☐	____________
other	☐	____________

ROOFS:

Indicate the type of roof system(s) that you have.

flat roof	☐	____________
Pitched with metal roof	☐	____________
Pitched with asphalt shingles	☐	____________
other	☐	____________

END OF SURVEY

Appendix F: Summary of Electrical Code

Electrical Code	Requirements: Ontario Electrical Safety Code 24th Edition/2009.
Electrical Services - Sizing	• Determine electrical load - for single dwellings of 80 sq.m. (860sq.ft.) and above is the greater of 100 amps or the calculated load. Rule 8-200.
Electrical Services – Layout	• Mount meter at 1.75 m (5' 9") plus or minus 100 mm (4") to center above finished (final) grade. Check your service layout for any additional requirements your Local Distribution Company may have with respect to the meter location. Rule 75-504, Specification 28. • Prepare a service layout and approved by the ESA. Contact the Supply Authority (electric utility) that supplies power to the building. It can be a sketch prepared by the supply authority together with the customer to determine the location of the service and meter, to what equipment and wiring the supply authority will require, and what equipment and wiring the customer may need to install for connection to the supply authority. • The meter-base location is determined by the local electrical distribution company using the Ontario Building Code, Ontario Electrical Safety Code, and any local requirements as guidelines. The local electrical distribution company should be contacted for a service layout to determine the acceptable meter-base location and the type of meter-base they require. Rule 6-408.
Electrical Service – Panel-board	• Do not install panel-board in clothes closets, bathrooms, stairways, rooms in which the temperature normally exceeds 30°C, dangerous or hazardous locations, locations where the headroom clearance is less than 2 m, nor in any similar undesirable location. The new service shall be located so as to be Code compliant. • No drywall is required behind the panel-board. • It can be installed in the kitchen with an unobstructed $1m^2$ area. Rules 6-206, 26-402. • Panel-boards in dwelling units shall be mounted as high as possible but with no circuit breaker position higher than 1.7 m (5' 6") above the finished floor level. Rule 26-402. • Minimum working space of 1 m (39") with firm footing be provided and maintained in front of electrical equipment such as panel-boards. Rules 2-308, 2-310. • An enclosure can be constructed above panel-board but not for storage and must be fully accessible for maintenance. Rules 2-308, 2-312 and 6-206 • Panel-board must be firmly secured to studs, joists, or similar fixed structural units. Plywood or similar material such as chip board is often secured to structural units to provide a firm flat backing to which the panel can be mounted. If the panel is mounted on a wall that separates a heated area from a non-heated area, then sufficient thermal insulation and vapour barrier is required. • Keep water heater 1 m (39") from the electrical panel. The Code requires a minimum working space of 1 m (39") with firm footing be provided and maintained about electrical equipment such as panel boards. The Code also requires that working space around electrical equipment be kept clear of all obstructions. Rules 2-308 and 2-312.
Electrical Service - Subpanel	• The subpanel can be fed from the main panel-board. Protect either by correctly sized fuses or a circuit breaker in the main panel. If an existing main panel has no spare circuit positions, then one of the existing circuits such as the stove may have to be transferred to the new sub panel to make room for the sub panel breaker.
Wiring and Wiring Methods	• A minimum air space of 25 mm (1") between the cable and heating ducts or piping. As an alternative, it is permitted to install a thermal barrier conforming to the Ontario Building Code to be installed between the cable and the heating duct so as to maintain an ambient temperature at the conductor of not more than 30° C. Fibreglass thermal insulation is one example of a thermal barrier that conforms to the Ontario Building Code. Rule 12-506.

	• The electrical code permits cables on the underside of the main floor joists in a basement provided the cables are mechanically protected either by location or other suitable means. Rule 12-514. • Non metallic sheathed cable is surface mounted at a height of less than 1.5 m (5') above a floor or in any location where it is subject to mechanical damage, the cable shall be protected by installing protective moulding, guarding, or piping over the cable. Rule 12-518. • Use Type ll exposed outdoor wiring in wet locations and suitable for exposure to the weather. Type NMWU cable may be run on the outer surface of a wall in residential applications. Type NMWU cable used in exposed wiring shall be adequately protected against mechanical damage where it is located less than 1.5 m above grade or is otherwise exposed to potential damage. Where wiring is installed in a conduit system above grade, it does not need to be suitable for wet locations and type NMD90 is permitted. Wiring installed in conduit below grade shall be suitable for wet locations (e.g. NMWU).
Lighting – Recessed Light	• The acronym "IC" means "insulation contact". This marking on a recessed lighting fixture (also called a can light or a pot light) means they are tested and certified to be installed in direct contact with or blanketed with thermal insulation. • Another marking you may encounter is "Type IC, inherently protected". The difference in the markings is the method of protection the fixture uses to prevent overheating. • NOTE: "Type NON-IC" fixtures can overheat dangerously and become a fire hazard when installed in contact with or blanketed with thermal insulation. The manufacturer's installation instructions shall also be followed in any installation. Rule 30-906.
Residential Outlets and Circuits	• Use GFCI in bathrooms and kitchen. • The Code requires either a 15 amp multi-wire circuit and 15 amp split receptacles or a 20 amp circuit and T-slot receptacles for kitchen counter outlets. A 15 amp rated GFCI (ground fault circuit interrupter) receptacle cannot be installed in compliance with either of these requirements. • The Code permits the use of 20 amp rated single branch circuits to supply 20 amp rated receptacles at kitchen counter work areas as an alternative to the traditional 15 amp rated split circuits and 15 amp rated split receptacles. Rules 26-712, 26-722. • Code compliant GFCI protection of the split circuit and receptacle option can be achieved by installing a 2 pole 15 amp GFCI circuit breaker at the panel-board. • Code compliant GFCI protection for the 20 amp non-split circuit option can be achieved by either installing a 20 amp GFCI circuit breaker at the panel-board or by installing a T-slot GFCI type receptacle at the outlet. • Receptacles located within 1.5 m of a sink shall be protected by a ground fault circuit interrupter (GFCI) of the Class A type. • Rules 26-700, 26-712, 26-722. • Two receptacles are permitted to be connected to the same circuit htat are located on either side of the kitchen sink. Rule 26-722.