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Building science and radiofrequency radiation: What makes smart and healthy buildings

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ABSTRACT

Radiofrequency radiation (RFR), used for wireless communications and "smart" building technologies, including the "Internet of Things," is increasing rapidly. As both RFR exposures and scientific evidence of harmful effects increase apace, it is timely to heed calls to include low RFR levels as a performance indicator for the health, safety and well-being of occupants and the environment.

Adverse biochemical and biological effects at commonly experienced RFR levels indicate that exposure guidelines for the U.S., Canada and other countries are inadequate to protect public health and the environment.

Some industry liability insurance providers do not offer coverage against adverse health effects from radiation emitted by wireless technologies, and insurance authorities deem potential liability as "high." Internationally, governments have enacted laws, and medical and public health authorities have issued recommendations, to reduce and limit exposure to RFR.

There is an urgent need to implement strategies for no- or low-RFR emitting technologies, and shielding, in building design and retrofitting. These strategies include installing wired (not wireless) Internet networks, corded rather than cordless phones, and cable or wired connections in building systems (e.g., mechanical, lighting, security). Building science can profit from decades of work to institute performance parameters, operationalizing prudent guidelines and best practices. The goal is to achieve RFR exposures that are ALARA, "As Low As Reasonably Achievable."

We also challenge the business case of wireless systems, because wired or cabled connections are faster, more reliable and secure, emit substantially less RFR, and consume less energy in a sector with rapidly escalating greenhouse gas emissions.

1. Introduction

Radiofrequency radiation (RFR) exposures are increasing rapidly with wireless technologies, but rarely are the terms "building science" and "RFR" used in the same sentence. Building science attends to the physical performance of buildings, the comfort, health, safety of occupants, and the larger natural and built environment [1]. "Science" includes physics and the electromagnetic spectrum, including RFR.

Building science considers the building *as a system* and devises effective solutions for design concerns. The primary system elements include: the building enclosure (building envelope); inhabitants (humans, animals, and/or plants); building services (electrical/mechanical/

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electronic systems); site, with its landscape and services infrastructure; and external environment (landscape, weather and micro-climate) [1]. To achieve a well-performing building, all these elements must be harmonized.

Historically, awareness of indoor environmental quality heightened with novel materials following World War II, and was bolstered with improved air-tightness during the energy crisis of the 1980s. Minimizing chemical off-gassing of composite materials, maintenance products and mold is advised to optimize indoor air quality and occupants' health [2]. Similarly, magnetic and electrical fields and currents with early electrical applications are also associated with adverse health effects. Assiduous adherence to electrical codes and best practices, and isolation of potentially problematic equipment, are among measures to address ongoing power-frequency, "dirty power" and ground current concerns [3,4].

Today engineers, architects, planners and others are challenged to keep abreast of research and policies that address potential harm from wireless technology. This paper builds on long-standing recommendations to expand the typical scope of building science to consider RFR [3,4]. It briefly describes RFR in the electromagnetic spectrum, use of wireless technology in "smart" buildings, and summarizes peer-reviewed, scientific research regarding biological effects on human and environmental health. Key reasons as to why action should be taken include potential liability risks when technology is not implemented safely. International measures and guidelines for lower RFR exposure are highlighted. Finally, practices are outlined and recommendations made to minimize the impact of RFR on public and environmental health in the design, construction and maintenance of safer, modern buildings.

Internationally, a broad range of standards and policies limit magnetic and electric fields over a broad range of frequencies, including RFR [5]. It is beyond the scope of this paper to address the full electromagnetic spectrum.

2. Radiofrequency radiation explained

2.1. The electromagnetic spectrum

The electromagnetic spectrum (Fig. 1) is a continuum ranging from low to high frequencies, associated with the longest to shortest wavelengths, respectively [6,7]. A distinction is made between high frequency non-ionizing versus higher frequency ionizing radiation that has enough energy to displace electrons and "ionize" atoms and molecules. Ionizing radiation includes ultraviolet light, X-rays and gamma rays. Below these frequencies, non-ionizing radiation includes visible and infrared light, and frequencies for wireless communications and radar. Lower frequencies are used to broadcast commercial radio and television, while alternating currents at 50 or 60 cycles per second or Hertz (Hz) are in power lines and building wiring.

RFR is sent wirelessly from a transceiver (e.g., Wi-Fi router) to another transceiver (e.g., computer) and vice versa. The RFR frequency range covered in guidelines and standards is generally from 3 kHz to 300 GHz and includes the microwave (MW) range. The terms RFR and MW are sometimes used interchangeably. Uses of frequency ranges overlap, so there are no precise boundaries for any particular technology. Information is encoded in the modulation (superimposed higher frequency irregularities) on a radiofrequency carrier wave. While the frequency of the carrier wave is stated in the manufacturer's specifications for various devices, the actual human exposure includes these overlain or superimposed signals [6]. Modern devices utilize multiple carrier frequencies.

Devices that receive and emit RFR include personal items that communicate wirelessly such as: cordless and mobile phones; computers, laptops, tablets and peripheral equipment; monitors (e.g., for babies, or medical purposes); toys, video game and entertainment systems; virtual reality headsets; GPS systems; and Bluetooth-enabled "wearables" such as for personal fitness. RFR-emitting equipment that may be installed in buildings includes: wireless routers and associated mesh networks; "smart" utility metering; identification and security systems; cell boosters; power transfer/battery charging stations; and the "Internet of Things" (IoT) such as building systems (e.g., heating, ventilation and lighting), and appliance monitoring and control.[1] These devices are designed to use a number of presently used plus new radiofrequency bands, from 600 MHz to GHz frequencies. Fifth generation or 5G frequencies that are being licensed by the U.S. Federal Communications Commission (FCC) will include lower frequencies used for television, through higher frequencies into the millimeter wavelength range (above 30 GHz) [9]. Higher frequencies provide greater bandwidth, albeit with shorter range and poorer penetration of structures and vegetation; these are discussed in Section 3.1.

Microwave ovens and other RFR-emitting devices (e.g., Wi-Fi and cell phones) rely on similar frequencies, but the power and signal characteristics are different. Ovens heat with 1000 Watts (W) of continuous-wave radiation, whereas wireless devices are lower power; for example a cell phone is a two-way microwave radio, using on average less than 1 W of modulated radiation. Wireless communications signals, however, are in short bursts, that are biologically active, independent of the carrier frequency [10,11]. Another key feature of anthropogenic electromagnetic radiation is polarization; i.e., that the waves may be in one plane [12].

2.2. Regulatory history of RFR in the United States

In the U.S., the FCC authorizes and licenses devices, transmitters and facilities that generate RFR [13]. The U.S. does not have federally developed safety limits, as the Environmental Protection Agency never developed biologically based limits. The current FCC RFR exposure limits were adopted in 1996 based on recommendations from the National Council on Radiation Protection and Measurements (NCRP) [14], the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers, Inc. (IEEE); specifically *IEEE C95.1–1991* and *ANSI/IEEE C95.1–1992*. None of these institutes have expertise in public health or biology. The FCC RFR exposure guidelines have not been substantially revised since 1996.

Presently, frequency bands between 9 kHz and 275 GHz have been allocated for various communications uses by the FCC [15].

2.3. RFR guidelines

The FCC RFR limits for public exposure reference three metrics: 1) the "Specific Absorption Rate" (SAR) is the rate at which RF energy is absorbed by human tissue; 2) power density, the rate of deposition of energy per unit area, is a function of the electrical and magnetic fields, at a particular frequency; and 3) the electrical field strength [7]. SAR limits apply to wireless wearable devices, cell phones and other items held close to the body. Power density limits apply to exposures at a distance, such as from cellular antennas and Wi-Fi.

2.3.1. Specific Absorption Rate (SAR)

The FCC and other governments' agencies require that all wireless devices such as cell phones or computers comply with SAR limits when the device is operating at its maximum power, before being placed on the market.

SAR is a measure of RFR energy dose to parts of the body closest to antennas, in the "near field," such as from the personal use of wireless devices. SAR is usually expressed in units of Watts per kilogram (W/kg) or milliwatts per gram (mW/g). The SAR for a given power density varies according to equipment details, the frequency and modulation,

[1] IoT is the comprehensive plan to connect billions of physical devices around the world to the Internet, collecting and sharing data.

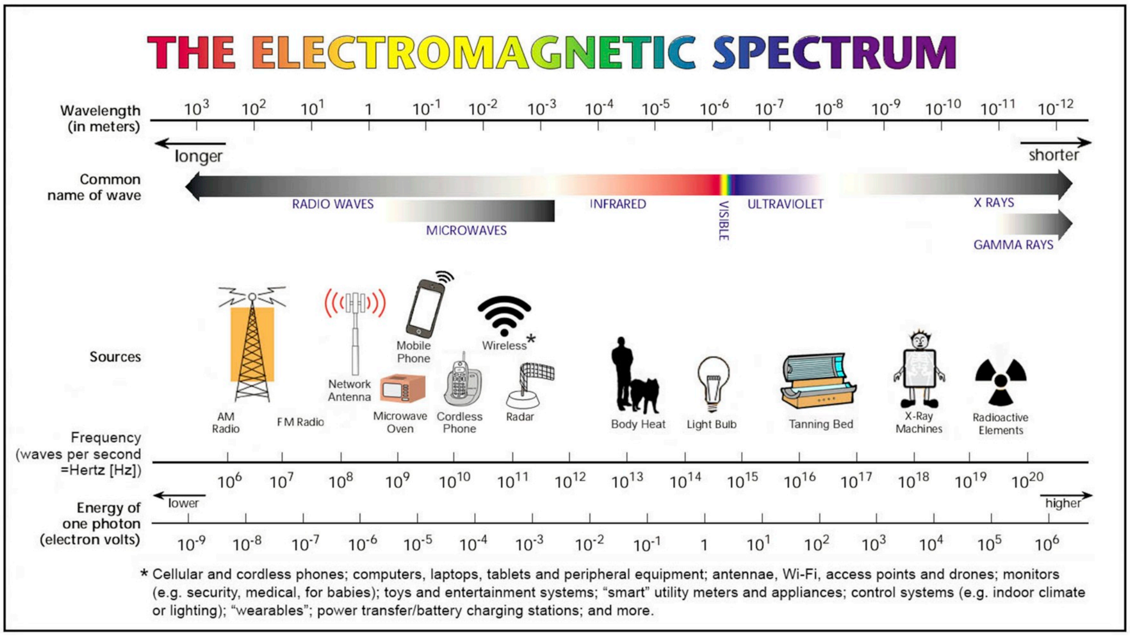

Fig. 1. The Electromagnetic spectrum (presented with permission) [8].

and the absorptive and reflective properties of the body or structure being exposed [7].

The FCC promulgated both public and occupational SAR limits. For the general public (commercial devices), the SAR limits for the head and the body are 1.6 W/kg averaged over a 1 g cube of tissue, and 4 W/kg averaged over a 10 g cube of tissue for ears, hands, feet, wrists and ankles [16]. Workers may be exposed to higher levels; occupational SAR limits are double those for the general public in the U.S., and five-fold greater for workers in "controlled environments" in Canada [17] as well as the many countries relying upon International Commission on Non-ionizing Radiation Protection (ICNIRP) guidelines [18].

Researchers have long criticized the SAR as an inadequate metric as it is measured in a mannequin – a liquid-filled phantom [19]. This does not capture the complex characteristics and interactions of living tissues' electromagnetic properties, or of RFR signals (e.g., the wave perturbations necessary to transmit information may cause additional biological impacts) [20]. FCC SAR limits and the measured SAR levels can be found in the manufacturer's instructions that come with every commercially sold wireless device, or on the manufacturer's website.

SAR testing protocols do not require cell phones and devices to be tested touching the body/skin or in novel configurations such as for virtual reality, despite the fact that this is the way they are often carried and used today [20,21,22]. Some cell phones are tested at as much as 25 mm separation distance. The national agency regulating radiofrequency radiation in France (ANFR) tested 450 cell phones in various configurations. The SAR exceeded the standard for 90% of the models that were tested as if they were contacting the body [23,24]. More than a dozen models were withdrawn from the market or had software updates to reduce RFR emissions.

2.3.2. Power density

Power density measurements address compliance in buildings or outdoor environments, such as when concerns are raised about RFR exposures from a nearby cell tower or from the Wireless Local Area Network (WLAN) system in a school. The FCC exposure limits range from 0.4 to 1.0 mW/cm^2 (4000 to 10,000 mW/m^2) [16] for commonly used frequencies.

Power density may be expressed as milliWatts or microWatts per square centimeter (mW/cm^2 or $\mu W/cm^2$), or milliWatts per square meter (mW/m^2).

For comparison, $1\ mW/cm^2 = 1000\ \mu W/cm^2 = 10{,}000\ mW/m^2$.

2.3.3. Electric field

"Electromagnetic" refers to both electrical and magnetic fields (EMF). Limits are established for electric fields, reported as volts per meter (V/m). Electric fields are commonly measured and reported during surveys of radiofrequency exposures, to characterize electromagnetic fields (EMF) across a broad range of frequencies [7].

2.3.4. Exposure attenuation

RFR reductions are generally reported as decibels. This is a non-linear, logarithmic scale, such that a signal that is 10 dB lower than another, is one tenth the signal strength of the comparator [25].

3. Information technologies and building science

Indoor environmental quality (IEQ) in more highly developed countries has advanced in terms of thermal comfort, air quality and construction for environmental performance (e.g., insulation), for example with guidance and classifications by The World Green Building Council [26] or Leadership in Energy and Environmental Design (LEED) [27]. These factors translate into familiar physical sensations of warmth, fresh air and comfort, versus cold drafts and stuffy air. Over the past decades, understanding of the modern sources of lower frequencies and now RFR within and surrounding building assemblies, and effects on inhabitants and surroundings, has gained recognition [3,28].

3.1. Developing technologies

Beyond Wi-Fi, a recent trend is the integration of wireless controls for lighting and heating/ventilation, as well as wireless security and audio/visual technology systems in buildings. "Smart buildings," with "smart systems" and "smart appliances" allow users to monitor and to control many interconnected mechanical and electronic systems via computers or "smart phones." Utility providers are utilizing "smart meters" for electricity, gas and water to transmit usage data electronically using RFR. Wireless charging stations for many items, from electronic devices to vehicles, may be additional sources of EMF.

Plans for the burgeoning IoT and 5th Generation (5G) wireless services are to transport large volumes of data quickly (e.g., for videos).

The proposed evolution of the "smart city" will imbue entire buildings and neighborhoods with higher levels of currently used frequencies, as well as the higher frequencies into millimeter wavelengths, which carriers plan to use in 5G [29]. A European Parliament report "5G Deployment: State of Play in Europe, USA, and Asia" explains how 5G radio emissions are different from those of previous generations because of their complex, highly focused, beam-formed transmissions, and that "it is not possible to accurately simulate or measure 5G emissions in the real world" [30].

Environments with very low RFR exposures can be achieved by choosing wired and fiber-optic cable connections, to buildings and throughout buildings. In fact, RFR is not only unnecessary for a "smart building;" wireless options will not match the bandwidth or reliability of fiber-optic or other cable options ("wired") [31]. Wired options are faster and more secure, and require much less energy to operate [29,32], making them safer for human and environmental health.

4. Adverse health effects of RFR

4.1. Introduction

In many countries, guidelines and standards to protect the public from adverse effects of radiofrequency radiation (RFR) are based on an assumption that harm results only from excessive heating of tissue (thermal effects); however, numerous scientific publications document that RFR affects living organisms at exposures within regulatory parameters, at "non-thermal" levels.

"Microwave assisted chemistry" accelerates particular chemical reactions with low levels of RFR [33,34], and has been commercialized [33,35]. In living systems, the acceleration of some chemical reactions would cause molecular damage, chemical imbalances and dysfunction, and is consistent with observations of significant effects in humans, animals, plants and isolated cells.

Effects observed in studies of humans exposed to non-thermal levels of RFR include: cancer; early childhood developmental problems; brain, sperm and DNA damage; as well as electromagnetic hypersensitivity.

4.2. Cancer

4.2.1. RFR classified as a possible human carcinogen

The adequacy of RFR regulatory limits was challenged in 2011 when an expert panel convened by the International Agency for Research on Cancer (IARC) of the World Health Organization classified RFR (100 MHz–300 GHz) as a Group 2B, *possible* human carcinogen, largely based on the human epidemiological evidence of increased risk of glioma [36,37], a type of brain cancer. This classification includes wireless frequencies from all types of RFR-emitting devices, including Wi-Fi. In 2019, an IARC advisory group recommended reassessment of the 2011 classification, in light of recent animal research [38].

4.2.2. Subsequent evidence supports upgrading the IARC classification

In 2018, Miller et al. concluded that as a result of human epidemiology, and animal studies published following the IARC 2011 panel meeting, RFR should be categorized as a Group 1 *known* human carcinogen [39]. Hardell and Carlberg came to the same conclusion [40]. Tobacco smoke and asbestos are in Group 1.

The main human evidence for this proposed classification upgrade is a large French epidemiological study [41], as well as a meta-analysis of pooled case-controlled studies in Sweden [42]. In addition, a 2018 Israeli occupational exposure study concluded that overall the evidence "make[s] a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1)" [43]. A case series also reports breast cancers associated with carrying a cell phone in the bra [44].

Canadian data (2001–2004) showed evidence of doubled risk of developing glioma for adults who used cell phones for 558 lifetime hours or more [45]. Consistent with the increasing use of cell phones, there was a statistically significant increase in incidence of primary malignant brain and central nervous system tumors in children and adolescents in the U.S. between 2000 and 2010 [46], and brain tumors subsequently became the most common malignancy in children and adolescents, with disease shifting to more aggressive gliomas [47].

Further supporting evidence came from three recent RFR rodent studies. The first two studies reported higher incidence of cancers in male rats exposed to RFR: 1) a $30 million study by the U.S. National Toxicology Program (NTP) of the National Institutes of Environmental Health Sciences (NIEHS), studied radiation simulating RFR intensity from cell phones [48]; and 2) a study by the Italian Ramazzini Institute [49] that was conducted at lower intensities (below FCC limits) designed to mimic radiation from cell towers. The tumors found in these large-scale studies were of the same histotype as in some human epidemiological cell phone studies.

A third large study demonstrated increased initiation and acceleration of tumor growth with RFR when the exposure was in conjunction with a cancer-causing chemical [50], replicating findings of a 2010 study [51].

4.3. Early life stages

During their rapid development, the embryo, fetus, infant and child are more vulnerable to many environmental insults, and impacts are potentially lifelong. Various life stages have different vulnerabilities

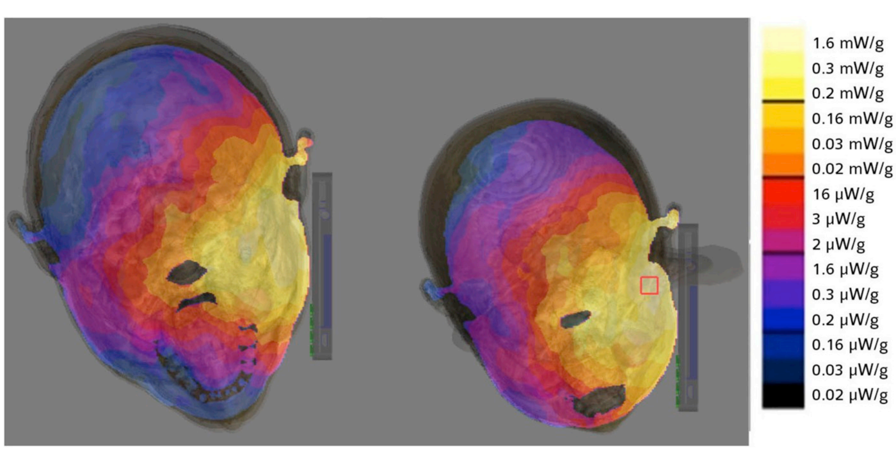

Fig. 2. Specific Absorption Rate (SAR) in adult and child (age 6 years) male heads with phone in talk position. The scale is 50 dB with 0 dB = 1.6 mW/kg. From work of Claudio Férnandez, 2018 [20] (used with permission of Environmental Health Trust).

and susceptibilities to RFR [52,53,54,55]. Modeling indicates that children absorb substantially higher RFR doses from cell phones, in deeper brain structures, than do adults (Fig. 2) [20]. Research has also found proportionately higher doses to tissues in children compared with adults, from wireless laptops and utility meters [56,57,58].

Research has linked exposure during pregnancy to adverse effects. The authors of a case-control study published in 2015 stated, "use of mobile phones can be related to early spontaneous abortions" [59]. Maternal mobile phone use during the first trimester of pregnancy may contribute to slowing or halting of embryonic development [60], possibly due to effects on membrane receptors in human amniotic cells [61]. A 2019 study of over 55,000 pregnant women and infants in four countries (Denmark, the Netherlands, Spain and Korea) linked maternal cell phone use during pregnancy with shorter pregnancy duration and increased risk for preterm birth [62].

Behavioral problems have been associated with prenatal and postnatal cell phone exposure. In five cohorts, Birks et al. found cell phone use by a pregnant woman to be associated with an increased risk for behavioral problems, particularly hyperactivity/inattention in her child [63], and Divan et al. reported behavioral problems in children up to seven years of age [64,65]. Studies of children and adolescents report possible associations of wireless technology use with addictions and depression [66], fatigue [67], altered baseline thyroid hormone levels [68], and poorer well-being [69,70]. Sage and Burgio discuss the damage from low levels of RFR to genetic material including DNA and nuclear structures in the cell, and potential mechanisms of child neurodevelopmental impairment [71].

A Yale University study found that when mice were exposed *in utero* to cell phone radiation, they had impaired memory and increased hyperactivity in adulthood [72].

Not only can RFR act along with carcinogens to promote tumor development [50], it also may synergize with toxic chemicals in other ways. For example, in a study of Attention Deficit Hyperactivity Disorder in children, ADHD was associated with mobile phone use for voice calls only in children who were also exposed to relatively high lead levels (lead is an established, potent neurotoxin) [73]. Further synergistic effects between RFR and various chemicals including nutrients (i.e., both beneficial and adverse) are described in a 2016 review by Kostoff and Lau [74].

4.4. Sperm

Three systematic reviews published from 2014 to 2016 [75,76,77] reported significant adverse effects on sperm quantity and quality, as well as DNA damage, from everyday RFR exposures. Animal studies reported testicular damage at 0.002 W/kg [78] and sperm damage at 0.024 W/kg SAR values [79].

4.5. Wi-Fi and other ambient RFR

Much of the RFR research reported thus far has focused on exposures to users of devices in close proximity (e.g., cell phones). More distant sources such as Wi-Fi access points or cell towers generally contribute less to exposures because RFR drops off quickly with distance from the source, following the "inverse square law" (levels are a quarter at twice the distance; one-ninth at three times the distance; etc.). Although exposure intensities from distant sources are usually low compared with devices in close proximity, simultaneous exposures are complex as devices connect to networks, people move around, and RFR may be reflected or absorbed by building materials, other surroundings, and inhabitants [80,81].

At any particular point in space and time, electromagnetic exposures are the sums of electrical and magnetic field vectors [7]. Of importance for health, effects (e.g., oxidative stress and consequences in tissues) may be cumulative over time, and these effects are modulated by other exposures to chemicals (nutrients as well as adverse substances) and other stressors [8]. 5G is to be deployed with multiple directional antennas, but future exposures are not well characterized [30], and less is known of future health outcomes from this technology.

In a comprehensive literature review, Pall states that "Wi-Fi causes oxidative stress, sperm/testicular damage, neuropsychiatric effects including EEG changes, apoptosis [cell death], cellular DNA damage, endocrine changes, and calcium overload," that the effects from continuous, long-term exposure may be cumulative, and that pulsed signals are more biologically active than a smooth carrier wave [82].

Impaired brain development and cognitive function, as well as addictive behaviors in children and adolescents are observed with exposure to RFR [71,81]. In a study of exposure to RFR in schools, 18 teachers wore "exposimeters" to continuously record exposures to a spectrum of RFR. Mean exposure levels varied widely according to activities in the classroom, but peak measures were up to 83,000 μW/m^2 [81]. The highest levels occurred when students were streaming video, and the lowest occurred when the teacher had a wired Internet connection in a classroom far from Wi-Fi access points and students' laptops were in airplane/flight mode [81].

Measurements of ambient RFR have been carried out in other settings, including a train station [80] and other Stockholm landmarks [83], and neighborhood surveys from a car [84]. Ambient measurements correlate moderately with personal monitoring.

In an extensive review, Dürrenberger et al. characterized RFR and emissions from infrastructure in micro-environments [85]. Exposures are typically underestimated, and experts, officials and citizens may be surprised at the differences among venues. These uncertainties make it statistically difficult to detect health effects, resulting in under-estimation of harms as well [86]. Although exposures generally meet government regulatory limits, they exceed precautionary recommendations [80]. Recent reviews of RFR assessments found higher levels in offices and public transportation [87,88].

Researchers in a Bavarian village followed a natural experiment over 18 months, when a central cell tower was installed [89]. They found dose-dependent dysregulation of stress hormones, according to peak RFR exposure measured at the doorstep [89].

Effects reported in RFR studies may be complex and non-monotonic (i.e., effects occur at lower exposure levels that do not manifest at higher levels) [48,50,90]. It is known that biological mechanisms are established whereby chemicals cause complex dose-responses, particularly for hormone-related effects (the endocrine system) [91,92].

4.6. Electromagnetic hypersensitivity (EHS)

As with other environmental exposures, some people are more susceptible (sensitive or intolerant) and overtly affected by RFR. Electromagnetic hypersensitivity (EHS) is also commonly termed electrical sensitivity, electrohypersensitivity, idiopathic environmental intolerance, or (historically) microwave sickness.

Common symptoms of EHS include headaches, cognitive difficulties, sleep problems, dizziness, depression, fatigue, skin rashes, tinnitus and flu-like symptoms [93,94]. Adverse reactions to wireless devices range from mild and readily reversible to severe and disabling, and individuals must greatly reduce their exposures to sources of electromagnetic radiation [95,96,97].

Surveys conducted in several countries at times ranging from 1998 to 2007 estimated that approximately three to thirteen percent or more of the population experience symptoms of EHS [98–101].

As well as being difficult to manage in the modern world, EHS is typically unexpected. The theory that EHS is merely a "nocebo" response – that it results from suggestion and worry over possible effects of electronic devices – is the opposite of experience. In a study of 40 people, their EHS was only recognized following a period of illness and self-experimentation [102]. Further research has confirmed that lived experience is not consistent with the nocebo hypothesis [103].

EHS is recognized as a disability and is accommodated in the U.S.

under the *Americans With Disabilities Act* [104]. Sweden recognizes EHS as a functional impairment [99]. In Canada, the condition is included under environmental sensitivities [97,105]. Legal cases for compensation, disability pensions and accommodation in various countries are discussed in Section 6.

Physicians' organizations' research, experiences, practices and statements over the years were summarized by the European Academy of Environmental Medicine (EUROPAEM) in 2016 [4]. Sensitivities vary among individuals, and symptoms may also occur with exposures outside the RFR range. The consensus of the *EUROPAEM EMF Guideline* is that the most important action for treatment and management of EHS is reduction and avoidance of pertinent exposures in locations where significant amounts of time are spent, especially in sleeping areas. Other recommended measures include a suite of healthy lifestyle measures such as nutrition, stress reduction and measures to avoid toxicants, as well as to reduce levels of toxicants sequestered in the body [4].

4.7. Rigorous systematic review of the scientific evidence, for public health, policy and regulation

As evidenced here, contributions of RFR to adverse effects on public health may be substantial [106,107]. Public policy, and safety guidelines and standards, should be based on all of the best available scientific evidence; however, there has never been a systematic review conducted according to international best practices [108] of the RFR evidence, upon which to base exposure guidelines.

Influence of biases and conflicts of interest has been documented as a serious concern for international authoritative bodies such as the World Health Organization-International Electromagnetic Fields (EMF) Project, and the International Commission on Non-Ionizing Radiation Protection [109–111]. The same is true for the national authorities in Australia [112], Canada [113–115], the European Commission [116], the United Kingdom [117] and the U.S [118]. Bias in original scientific studies is evident in that studies funded by industry are less likely to identify adverse effects than those that are independently funded, and even less likely to conclude that adverse effects exist [119–121].

An important step towards resolution of the adequacy of guidelines and standards to protect public health, as well as policy and practical responses for individuals who experience EHS, would be a thorough systematic literature review conducted by independent, knowledgeable specialists. This would examine all of the RFR literature dating back to the identification of health concerns with the development and deployment of radar during World War II, including the studies in the 1971 review by Dr. Zorach Glaser [122].

Key features of this type of review include that all steps and findings must be transparent, such as bibliographic search methods, study selection, data extraction and meta-analyses, quality assessment and the weight of evidence analysis [108].

5. Environmental impacts of cell tower and radiofrequency radiation

Built and natural environments are interconnected. Biological systems are integrated, complex and operate using minute electrical charges combined with precise chemical signals. These mediate complex functions such as development, reproduction and cognition. Recent research has demonstrated adverse effects of radiofrequency radiation (RFR) on environments and wildlife, including birds, amphibians, insects, fish, mammals and plants [123–125]. For example, trees near cell towers can become visibly unhealthy on the side facing a cellular antenna, and can die prematurely [126].

A diverse array of species depends upon the Earth's low-level magnetic field to navigate for migration, homing, breeding, foraging and survival. RFR can have significant long-term impacts on the natural environment via disruption of normal positioning and orientation abilities as well as other complex cellular and biologic processes. Incremental effects may be only slowly recognized as species and ecosystems decline.

Small deposits of the iron-containing mineral magnetite act as magnetoreceptors to sense the Earth's magnetic field in a variety of organisms, including bacteria, insects, fish, birds and mammals [127–129].

Some bird species are strongly influenced by the low-intensity magnetic fields of the Earth for directional reference. Newer studies suggest that light-dependent cryptochrome photo receptors in birds' eyes are also sensitive to magnetic forces, and communicate with the brain [130,131].

RFR can interfere directly with magnetoreception in birds, disabling their avian magnetic compass [132]. A series of double-blinded studies replicated over several years demonstrated that migratory European robins lost their ability to orient and navigate in a city with high background “electromagnetic noise” and broadband frequencies [133]. Effects can be complex, as illustrated by findings that some birds can be more sensitive to weak broadband than to stronger fields [134,135].

Bees use magnetite crystals in their abdomens for navigation [136]. This sensory modality can be disrupted by electromagnetic fields, causing a loss of colony strength [137–140]. Scientists are increasingly concerned about the impacts of wireless radiation on the worldwide decline of domestic bees and colony collapse disorder [141,142]. Other insects are also adversely affected by RFR [142–145].

Review articles indicate that the weight of evidence is that RFR acts as an environmental toxin with ecosystem-wide harm from increasing ambient RFR emitted by cell towers and other RFR infrastructure [146–152].

6. Liability

Some industry liability insurance providers do not provide coverage against adverse health effects from RFR. Lawsuits for RFR health-related conditions are underway, and some have been successful in different countries.

6.1. Insurance industry and liability related to radiofrequency radiation

Insurers have declined to provide coverage to wireless product manufacturers and U.S. mobile operators for health damages from their products and networks since the early 2000s [153]. Insurers often exclude or limit coverage for the risk from electromagnetic fields (EMFs) posed by commercial general liability policies, decline policyholders in the wireless industry, and only provide coverage via pollution liability policy enhancements.

Insurance authorities also address the risks of electromagnetic fields. In 2014, the Swiss RE report *New emerging risk insights* listed the potential impact of the “Unforeseen consequences of electromagnetic fields” as “High” and examined further incremental risk associated with smart cities [154]. In its 2019 update, Swiss Re identified the top two emerging risks to be “digital technology's clash with legacy hardware, and potential threats from the spread of 5G mobile networks” [155].

In 2010, the Emerging Risk Team of Lloyds issued a white paper [156] indicating that the potential risks to insurers from health damage claims associated with cell phones and wireless radiation are comparable to those posed by asbestos. The 2013 Lloyds Risk Index lists “harmful effects of new technology” as an increasing environmental risk [157].

Some corporate insurance policies feature a general exclusion section that explicitly prohibits liability for injury or property damages from electromagnetic fields. This is considered to be a standard across the North American insurance industry [158].

Insurance company policies will often define electromagnetic radiation as a “pollutant.” According to the AT&T Mobile 2012 Insurance policy, “Pollutants” mean: “Any … artificially produced electric fields, magnetic field, electromagnetic field, sound waves, microwaves, and all artificially produced ionizing or non-ionizing radiation and waste." [159]. Policy enhancements can be purchased to cover environmental pollutants, which include EMFs [160,161].

The Austrian Worker's Compensation Board (AUVA) commissioned the Vienna Medical University to research effects of cell phone radiation on the brain, immune system, DNA and proteins, and published a series of reports that present the research evidence and conclude by recommending precautions to reduce exposure [162,163].

6.2. Summary of 10 K reports

Publicly traded companies issue annual 10-K reports to the U.S. Securities and Exchange Commission, summarizing the company's financial performance and status. Mobile operator reports identify potential liabilities for health damages from exposure to wireless devices as a risk, and provide no assurances that their products or equipment will be safe in future years.

Crown Castle states in their 2017 Annual Report [164], "If radio frequency emissions from wireless handsets or equipment on our communications infrastructure are demonstrated to cause negative health effects, potential future claims could adversely affect our operations, costs or revenues."

Verizon's 2017 Annual Report [165] states, "… our wireless business also faces personal injury and wrongful death lawsuits relating to alleged health effects of wireless phones or radio frequency transmitters. We may incur significant expenses in defending these lawsuits. In addition, we may be required to pay significant awards or settlements."

6.3. Lawsuits related to electromagnetic fields

In the U.S., the first cell phone cancer case was filed in 1992 and was followed by a series of cases that were either settled by confidential resolutions or dismissed due to lack of evidence or lack of authority of the court [166]. At the time of writing, there are thirteen active consolidated cases with defendants alleging their brain cancers were from cell phone use [167]. In 2017, Italy's highest court recognized a causal link between development of a brain tumor and cell phone use, and awarded social security payments [168].

Internationally there are several lawsuits related to cell phones and cancer and disability from EMF exposures. For example, Australian [169] and Spanish [170] courts have awarded disability to workers claiming sensitivity to electromagnetic radiation.

In January 2019, an Italian court ordered the government to launch a campaign to advise the public of the health risks from mobile and cordless phones [171].

7. International actions to limit public exposure to RFR

Some international governments have passed legislation (Table 1), and health and environmental authorities in numerous countries, regions and cities have issued recommendations (Table 2) to reduce exposure of the public to radiofrequency radiation (RFR). Measures frequently focus on children's vulnerabilities [172], identifying "sensitive areas" with stricter exposure limits where the young sleep, play and learn.

5G, the next generation of wireless technology, will utilize frequencies presently in use, plus higher frequency millimeter waves not previously used for commercial telecommunications. Regional governments, such as the Cantons of Geneva, Vaud and Neuchâtel in Switzerland, are issuing decrees calling for moratoriums on the rollout of 5G technology until the health effects are better understood [173–175].

7.1. Regional U.S. Guidelines and recommendations to limit RFR exposure in schools

In addition to national policies to reduce children's EMF exposures, several authorities in the U.S. have issued guidelines for schools. In 2014, the Collaborative for High Performance Schools (CHPS) [189], the leading organization for healthy schools in the U.S., first published recommendations to minimize exposure to both Extremely Low Frequency (ELF) magnetic fields and RFR. Criteria for "Low-EMF Best Practices" include:

- providing a wired local area network (LAN) for Internet access throughout the school;
- disabling all wireless transmitters on all devices;
- ensuring that all laptops or notebooks have an Ethernet port and a single physical switch to disable all wireless radios;
- providing easily accessible hard-wired phones for teacher and student use;
- prohibiting the installation or use of DECT cordless phones; and
- prohibiting the use of cell phones and other personal electronic devices in instructional areas.

In 2016, the New Jersey Educational Association [190] and the Maryland Children's Environmental Health and Protection Advisory Council (CEHPAC) [191] also issued recommendations to reduce RFR in school classrooms, including, "if a new classroom is to be built, or electrical work is to be carried out in an existing classroom, network cables can be added at the same time, providing wired network access with minimal extra cost and time."

Measures to reduce exposures regarding personal devices are listed in the Appendix.

8. Recommendations for the building industry

Rapidly evolving technology is resulting in an evolution of building systems, moving to integration of air quality control, power management, surveillance and access, communications and data management, etc. in "smart" buildings. Although wireless "Internet of Things" may be popularized as central to "smart" infrastructure and conveniences, key features can readily be physically connected non-wirelessly. Sinopoli detailed essential elements of design, construction (installation of cables/wiring), integration and operation of networked systems to improve indoor environments and function, and achieve efficiencies in indoor spaces [192].

Electromagnetic interference is another reason to minimize radiofrequency radiation RFR [193]. It can degrade operation of wireless systems (e.g., Wi-Fi), and sensitive electronic equipment (wired or wireless) such as for entertainment recording or medical applications. Addition of cell towers in proximity to unshielded areas (indoors or outdoors) can also cause signal interruptions and static. In the extreme, wireless systems can be shut down by malicious attack with strong signals "drowning out" signals on designated frequencies.

Health care policies have evolved to protect operation of essential equipment. Mobile phones were initially forbidden in hospitals due to risks of interference with operation of sensitive equipment. Based on limited study, it is now recommended that wireless devices be kept at a distance from sensitive equipment (e.g., in intensive care units [ICUs]) [194]. Today, wireless access for patients and the public is often provided in hospitals, and wireless devices are common in healthcare [195]. There is no evidence of clinical benefit, and reviews did not investigate potential clinical harms [195].

For any systems that are not "wired," architects, builders, owners and inhabitants all must operate within constraints of regulated RFR exposure levels. RFR exposure limits vary among jurisdictions, with the highest permitted personal exposures in the U.S.A. and Japan. Many countries adhere to the International Commission on Non-Ionizing

Table 1
Examples of national legislation limiting RFR.

Year	Country and Reference	Legislation
2016	French Polynesia [176]	Banned marketing of cell phones to children. Prohibited wireless in nursery schools.
2015	France [177]	Banned Wi-Fi from nursery schools. Decreed that in schools Wi-Fi be turned off as default, unless the teacher uses it for specific instruction. Wi-Fi hotspots must be labeled.
2014	Korea [178]	Mandated SAR labeling on cell phones and portable devices. Public health recommendations to reduce exposure to cell phone radiation.
2013	Belgium [179]	Banned marketing of cell phones to children below age 14. Phones designed for children below age 7 years are prohibited from sale.
2012	India [180]	Limited RF-EMF exposure levels from cell antennas to 1/10th of International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. Required SAR labeling on phones.
2012	Greece [181]	Forbade installation of mobile phone base stations on the premises of schools, kindergartens, hospitals or eldercare facilities.
2010	France [182]	Required that cell phones be sold with a headset and recommendation to limit exposure to the head. Cell phone advertising aimed at children below age 14 years was banned.

Radiation Protection (ICNIRP) recommended guidelines for power flux density, electrical fields and SAR for various frequencies [196]. Exposure limits range widely, for example in terms of power density at 900 MHz, as summarized in Fig. 3.

8.1. Building guidelines for lower electromagnetic field (EMF) exposures

Green building standards for occupants' health put great emphasis on indoor air quality, and the electromagnetic characteristics of the indoor environment are beginning to gain more widespread attention. This is exemplified by the aforementioned CHPS "Low-EMF Best Practices" in the U.S [189].

In Austria, Germany and Switzerland, however, electromagnetic fields and radiation exposures have long been a green building consideration. In Germany, the first precautionary exposure guideline for sleeping areas (SBM-2015) [28] was issued by Baubiologie Maes in cooperation with the Institute of Building Biology and Sustainability (IBN) in 1992. Based on thousands of electromagnetic assessments, radiofrequency radiation (RFR) levels in the bedroom below 0.1 μW/m^2 are considered "no anomaly." RFR levels above 1000 μW/m^2 (1 mW/m^2) are considered an "extreme anomaly."

The Total Quality Building Assessment Tool (TQB) is a widely used green building rating system [199], addressing a broader range of parameters than the Leadership in Energy and Environmental Design (LEED) rating system [27]. Since its inception in 2001 the TQB tool has included low-intensity EMFs and radiation – both low-frequency alternating magnetic fields and RFR. The TQB awards points in the planning and final testing stages for low levels of RFR.

The European Academy for Environmental Medicine (EUROPAEM) EUROPEAM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses [4] details recommendations for precautionary threshold electromagnetic exposure levels, including for RFR.

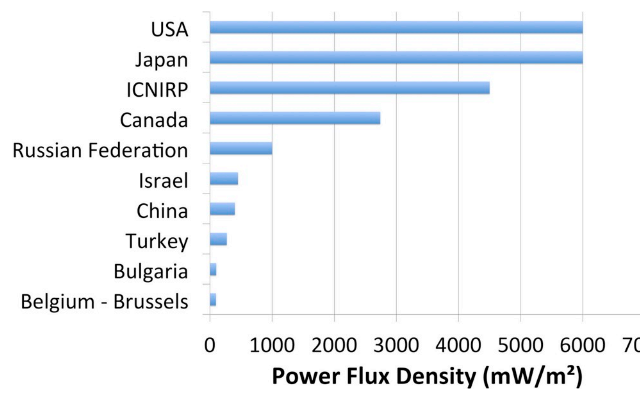

Fig. 3. International RFR power flux density exposure limits at 900 MHz [197,198].

To put these recommendations into context, the precautionary thresholds fall somewhere between the low natural background level and official exposure limits (Fig. 3). For comparison, Table 3 summarizes prudent, precautionary recommendations of European specialists.

The guiding principle of "as low as reasonably achievable" (ALARA) was introduced as early as the 1950s to protect against ionizing radiation [200] and holds true for many toxicants to the present day [91], including RFR [201]. RFR levels in indoor environments can be minimized by integrating the principal of ALARA (minimize emissions and exposures, maximize distance and use protection) [202] into selection of the building location, design and materials, as well as choices of electrical, monitoring, control, surveillance and other systems and services.

Table 2
Examples of national policies, public health advice and medical organization recommendations.

Year	Organization and Reference	Advice and Recommendations
2017	Athens Medical Association [183]	Sixteen recommendations to reduce human exposure to wireless radiation
2016	France - National Decree [184]	Reduced EMF exposure of workers, especially pregnant women
2016	US - American Academy of Pediatrics [185]	Ten recommendations to reduce exposure to cell phone radiation
2015	Cyprus National Committee on Environment and Child Health [186]	Public service videos and brochures for families about how to reduce cell phone and wireless exposure
2009, 2015	Finland - Radiation and Nuclear Safety Authority [187]	Recommendations to reduce RFR exposure, especially of children
2011	Parliamentary Assembly, Council of Europe [188]	"The potential dangers of electromagnetic fields and their effect on the environment" recommends As Low As Reasonably Achievable (ALARA), awareness, precautionary approaches, transparency, research, etc.
2010	France - National Public Health Agency [182]	An awareness campaign about ways to reduce RFR exposure

Table 3
Precautionary guidance RFR exposure levels [4,199].

		Exposure to 900–1800 MHz RFR (mW/m^2)
TQB Tool	Planning stage	
	10 points (best)	≤1
	5 points	≤3
	0 points	> 3
	Final stage	
	10 points	S ≤ 0.01
	8 points	0.01 mW/m^2 < S ≤ 0.1
	6 points	0.1 mW/m^2 < S ≤ 1
	4 points	1 mW/m^2 < S ≤ 3
	0 points	> 3
EUROPAEM 9001800 MHz		
	Daytime	0.1
	During sleep	0.01
	Sensitive Populations	0.001
Natural Background		0.000000001

8.2. Strategies to eliminate or minimize RFR exposures from sources within buildings

As exemplified in section 8.1, engineers, architects, designers and planners have a unique opportunity to create healthier living, learning and work environments by reducing use of wireless technologies and thereby reducing levels of RFR. Although it is simpler, preferable and less expensive to implement RFR-free options during the initial design and construction stages, existing buildings represent many opportunities for improvements.

8.2.1. Connect necessary technologies with cables

An important first step to minimize levels of RFR within buildings is to eliminate indoor sources of RFR, and to connect all technologies via wire or fiber cable ("wired").

Consider alternative approaches to wireless technology. Recommendations include:

- Neighborhood infrastructure with cable access for high-speed, wired telephone and Internet;
- Within buildings use cables, preferably shielded, in Local Area Networks (LAN) to provide wired access points for all networking and data transmission, including wired connections for modems, routers, Internet and media; lighting, heating, ventilation, air conditioning (HVAC), thermostats and humidistats; surveillance and security systems; fire detection and response (e.g., sprinklers); pool equipment such as pump and treatment controls, etc.;
- Install easily accessible wired (not cordless) phones and prohibit installation and use of cordless phones;
- Throughout the building, provide connections to hardwired CAT6 or CAT7 Ethernet cables, preferably shielded, to service devices such as computers, tablets and other devices. Use wired peripherals and accessories. Ensure that all wireless features are turned off or disabled;
- Install wired RJ11 phone jacks for corded and landline telephones; and
- Use analog, non-transmitting utility (water, electricity, gas) meter options, that do not transmit data wirelessly.

8.3. Strategies to minimize the RFR exposures from external sources

8.3.1. Building location and landscaping

To achieve very low RFR levels, new buildings may be located in a low-RFR environment, for example at a distance from cell towers, radio and TV broadcast towers, and radar sites (e.g., airports). Evaluate the proposed location with professional grade RFR equipment to determine ambient RFR levels and sources. Sites in valleys may be at least partially protected from regional sources of RFR by surrounding hills, as may underground structures by intervening earth that absorbs RFR, depending upon composition and moisture level [203]. Conductivity and permittivity of soil increases with moisture content [204]; MW radiation is strongly absorbed by water.

Vegetation, with its significant water content, will absorb some RFR. While foliage of tall deciduous or evergreen trees may present challenges to wireless service providers, absorption of RFR from nearby antennas may also harm vegetation [126].

8.3.2. Building materials and shielding

RFR may be either reflected or absorbed by building materials, and there is a continuum of how opaque building elements are to RFR [204]. Shielding with highly absorbing or conductive materials can be very effective to reduce RFR originating from outdoors sources [205].

Many building materials such as wood and wallboard are largely transparent to present day RF signals, but research is intensifying on RFR-absorbing materials and fabrics that contain metals or carbon based substances (e.g., nanotubes) [206,207]. Construction materials are less effective barriers to RFR in the MHz and lower GHz frequency ranges, as currently used for cell phones, than for higher GHz frequencies planned for 5th generation (5G) technologies [208].

Absorption rather than reflection offers clear advantages for protection from RFR, and considerable relevant research has been devoted to materials that absorb radar [205]. Thick layers of dense building materials such as concrete offer some potential to absorb RFR and thereby reduce levels, particularly in the GHz range. Early research indicating high attenuation [209] was not precisely replicated with drier samples.

Conductive materials must be used with care and caution because reflections may result in unanticipated exposures. Totally enclosing a space with reflective materials (e.g., metal) results in a "Faraday cage." Radiation from sources within the "cage" reflects from one surface to another and this can result in higher local levels than would be the case if RFR was transmitted or absorbed by structural materials and furnishings.

To shield against incoming RFR from cell antennas, Wi-Fi networks and radio broadcast towers, shielding may be integrated across the entire building envelope or selected rooms or zones of a building.

Low-E windows coated with a transparent layer of metal oxides (developed to reflect infrared to retain heat in buildings and reflect ultraviolet light from the outdoors) and metals reflect RFR. Exterior shielding may be achieved with metal cladding/roofing, metal window and door frames, metal or metal-clad doors, low-E windows, metal screens, RF window film, and fine metal mesh or radiant barrier foil integrated into the building envelope. Further options indoors include high quality carbon-based shielding paints or fine metal mesh, and RF-shielding drapes/sheers. Conductive shielding materials including paint must be electrically connected and properly grounded.

It is essential to recognize that within shielded spaces, devices must have all wireless functions turned off. Poor network connections for cell phones will result in stronger RFR signals from the device itself, with potentially four-fold higher exposure to the user [210], and reflections from metal shielding may result in yet higher exposures. Thus, prominent explanatory safety notices are necessary to ensure that all cell phones are "off," set to "airplane mode," or are left outside of the low-RFR shielded zone. Options to meet occupants' needs include provision of accessible corded landline telephones to which cell phone calls can be forwarded, and provision of wired connections for devices.

Whatever options are used to achieve low RFR levels, it is necessary to verify final results with measurements using an RFR meter. RFR from equipment and exterior sources, along with reflections, and interactions with conductive infrastructure can result in complex, unanticipated patterns of electromagnetic fields, including hotspots [193,208]. Periodic checks are necessary to ensure that additional equipment, furnishings or modifications, indoors or outdoors have not increased RFR levels.

Each make and model of RFR meter or measurement instrumentation has different specifications. To confirm the effectiveness of an RFR meter, obtain a third-party calibration report from a certified testing facility.

8.3.3. Partial RFR-Reduction measures for internet connectivity in buildings

In homes, schools, and workplaces, the installation and exclusive use of wired Internet access and electronic communication among devices mitigates the RFR emissions from internal network systems.

During any time that a wireless function is enabled, on stationary or mobile equipment, routine signals to maintain connections will expose building occupants to RFR, whether or not the device is actually being used.

In situations where decision makers decide not to hardwire a building immediately and instead continue with wireless connectivity, some partial measures may partially reduce unnecessary exposure. Importantly, these partial reduction steps do not equate with complete RFR mitigation, do not ensure safety for occupants, and do not reduce liability.

Recommendations include:

- Connect routers to a power source using a timer, to power off when not routinely in use, such as at bedtime;
- Wireless routers and access points should have an easily accessible switch to turn them off when not in use;
- Choose routers that can accommodate wired input, equipped with an accessible on/off switch for wireless features, and use a wired connection to a wired modem, to provide Internet connection when the wireless function is turned off;
- Avoid modems that also act as public “hot spots;”
- Do not install wireless access points near bedrooms or other highly or frequently occupied spaces;
- Clearly label wireless access points and areas where wireless antennas are in use;
- Use wired connections for HVAC monitoring and control, lighting, security and other fixed monitors and controllers;
- For improved security and lower carbon footprint, as well as reduced RFR, access data and controllers via a wired connection;
- If a wired analogue utility meter is not an option, mount the wireless meter at a distance, shield appropriately and direct signals to where they are read. Locate wireless meters away from high-use areas, particularly bedrooms; and
- If the building is mostly shielded, but has an unshielded zone for wireless device use, ensure that there is signage informing people: 1) of the RFR exposures along with wireless access (and alternatives onsite); and 2) the need to have all wireless functions turned off in shielded zones.

Implementation of partial measures will continue to expose occupants to RFR at levels associated with adverse effects. Measures such as turning off wireless features when not in use still result in RFR exposures, are not ALARA, and ideally will only be used in the interim while wiring plans are being developed and implemented.

8.4. Sensitive and vulnerable individuals

All of the above and more may need to be implemented to reduce RFR adequately in indoor and outdoor environments, to accommodate sensitive individuals. This will often require engaging an EMF expert, because the behavior of electromagnetic fields, currents and radiation is complex and difficult to predict. Sensitive individuals must be consulted throughout the duration of any renovation or building project, because individuals may react differently to various electromagnetic exposures. These individuals may also be sensitive to indoor air quality, so they must be involved in selection of materials for construction or retrofitting [2].

8.5. Challenging the business case of wireless systems

Not only are multiple risks invoked by choices of wireless instead of wired technology, there are many advantages to wired solutions.

Wireless networks [29,211]:

- continue to be about 100 times slower than wired systems;
- are unreliable, and more prone to both latency and delay issues;
- consume significant amounts of energy – more than wired – and are not sustainable;
- increase the points of vulnerability; and
- increase the security and privacy risks to personal and business data.

Some companies are cautioning that deployment of wireless 5G and beyond will be hampered by current regulatory power density exposure limits [212,213].

9. Discussion and conclusion

The breadth of peer-reviewed scientific research demonstrating biological effects of radiofrequency radiation (RFR) below current guidelines and standards highlights the need to further develop and codify pertinent building technology standards and guidance. Public health risks, accessibility needs, industrial liability and international precautionary actions indicate that RFR is an important performance parameter in building science.

Parallel with rapid innovation in wireless technologies, and the increasing RFR both inside and outside building structures, building science must also innovate to include alternative, physically connected technologies and systems. This is important to achieve accessibility and a building's success. Ensuring that the health and safety of occupants are not compromised requires those in the building science professions to develop and apply needs and means assessments, as well as best practices for methods and models for communications, with RFR wireless technology as a less-preferred option.

Research and knowledge transfer are needed to develop, publish, and encourage compliance with explicit directions for the integration of wired communications technologies in the design, planning, engineering, construction, operation and life cycle of a building.

Building science has embraced ecology and sustainability as core tenets in building performance. Currently, modern technologies minimizing RFR exposures offer an under-addressed opportunity for “smart” buildings also to be healthy – for their occupants, and for natural and built environments.

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Appendix

General Safety Tips to Reduce Radiofrequency Radiation (RFR) Exposure from Personal Devices

- Keep cell phones away from the head and body, and keep wireless devices at a distance, and off of laps.
- Make only short or essential calls on cell phones.
- Use text messaging instead of voice calls whenever possible.
- As much as possible power off phones and personal digital devices, or set on airplane mode with Wi-Fi, Bluetooth, Data, Mobile Hotspot and Location off.
- Avoid sleeping next to cell phones or wireless devices; power them

off at night. If a cell phone must be used as an alarm clock, turn the phone to airplane mode, or use a separate battery-powered clock.

- Keep non-prescription electronics out of bedrooms. If you depend upon medical devices with wireless functions, check how often they may be set to "airplane mode," and ask your health care provider about adequate alternatives that do not emit RFR.
- Avoid charging phones and devices near beds.
- Use a corded (not cordless) home phone (wired [not wireless] VoIP or landline) whenever possible, especially for long voice calls.
- Pre-download videos and music rather than streaming.
- Minimize the number of apps running on wireless devices.
- Choose wired Internet connections instead of wireless systems, whenever possible. Provide wired Internet connections for others.
- If Wi-Fi cannot be entirely eliminated, put the Wi-Fi router on a timer to turn off when not needed (especially while sleeping).
- When digital devices are connected with wired Internet connections, turn off the Data, Wi-Fi and Bluetooth (in device settings) and turn off the Wi-Fi on the router.
- Request wired options and provide them to others, such as for computers, laptops, tablets, printers, gaming consoles and handsets, mouse, keyboards, video cameras, speakers, headphones, microphones and other accessories.

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