Building Entry Loss For A Morton Building

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The Healthy Housing Research Institute is investigating methods of building housing that will protect its occupants from harmful microwave signals while inside. The first building style to be investigated is a metal skin building by Morton Building Company. This is a nation wide company that has been building this general type of structure for over a century. If the fields inside compared to the fields outside are sufficiently low, then people would be able to build houses with this technology where they live and work. A family member with Electromagnetic HyperSensitivity and/or Multiple Chemical Sensitivity (EHS/MCS) could have better health than possible with existing housing stock, without unduly disrupting family life by moving to the mountains.

A 30' by 48' building with 10' ceiling on a concrete slab has been built. It is permitted as a shop/office, but exactly the same size and technology could be built as a house by adding bathrooms and a kitchen. Morton will build interior walls with sheetrock wall covering if desired, but their preference is to use the same metal siding on the inside walls and ceiling as on the outside. Such metal siding on the inside essentially makes the house into a double wall Faraday Cage, with promise for quite low field strengths on the inside. Signals will not propagate directly through a metal panel. However, signals will pass through the windows, through the seams between panels, around the doors, etc. A mathematical calculation of the reduction in field strength from outside to inside is *extremely* difficult, so we will directly measure the reduction.

This measurement has been done on many buildings over the years by those interested in Building Entry Loss (BEL). These are people who want cell phones and WiFi to *work* inside buildings (as opposed to me). One can Google the phrase to get papers on the topic. First, a little background.

An electromagnetic wave (e.g. a signal radiated by a cell tower) can be described in terms of its electric field E, measured in volts per meter, or its power density S, measured in watts per meter squared. The power density might also be expressed in milliwatts (mW) per square meter, or microwatts (μW) per square meter, where 1000 mW = 1 W and 1,000,000 μW = 1 W.

It is customary to express ratios of signal strength in decibels (dB) where

$$dB = 20 \log \frac{E_2}{E_1} \tag{1}$$

dB	S_2/S_1
3	2
10	10
20	100
30	1000
40	10000

Table 1: dB values for certain power density ratios

If we are calculating with the ratio of power densities, then we use the formula

$$dB = 10 \log \frac{S_2}{S_1} \tag{2}$$

This means that we get the same number of dB whether we measure volts per meter or watts per square meter. Some meters will display either electric field or power density. The Tenmars TM-195, for example, measures the electric field, and then performs an internal calculation to be able to display the power density. The Gigahertz Solutions HF38B displays only power density. I don't recall seeing this detail in their literature, but I suspect they actually measure electric field and then calculate the power density, just like the TM-195.

Some useful values for dB for given power ratios are given in the following table.

If the power density increases by a factor of 2, we call it +3dB. If it decreases by a factor of 2, we call it −3dB. A factor of 10 is 10 dB, and every additional factor of 10 in the power level adds another 10 dB.

Measurement of power density around buildings is always difficult. There will be reflection of a portion of the wave when it hits a surface. There will be attenuation when the wave propagates through a lossy region. There will be refraction, diffraction, and multipath effects. For example, a cell tower signal may reach your cell phone directly, in a straight line from the cell tower. But the same signal may leave the tower in a slightly different direction, but then get reflected or diffracted toward your cell phone with what is called a phase shift. If the two signals arrive with the same phase, they will reinforce each other, to give a stronger signal than would be expected otherwise. Seeing an increase up to a factor of 2 is not uncommon. But if the two signals are out of phase they will tend to cancel each other. The combination can have a value close to zero. At such locations with multipath, the measured power density can easily change by a factor of ten over distances of just a few feet or even a few inches. There will always be multipaths within a building, so to obtain a meaningful value for the power density inside the building, it is common to take measurements at a number of locations and then take an average.

There are several theoretical issues that could prevent us from arriving at a really meaningful value for BEL, regardless of how many averages we take. One issue is linearity. Do we get the same BEL (a ratio of field strength inside to field strength outside) if the source of the signal doubles in strength? Another issue is frequency. Does the BEL change drastically if the frequency changes by a small amount? A Morton Building is different from other building types that have been tested. Issues that could be safely ignored with most buildings may now need to be considered.

The Morton Building is built at a spot where cell phones read a solid 2 or 3 bars out of 5. Call quality is good. On Jan. 19, 2019, my dirt contractor was inside the building with me. I was showing him some of the finishing touches. His cell phone rang and he answered. It was his wife. She immediately commented on the terrible call quality. He quickly moved outside to finish the conversation. So the building degraded the reception from 'good' to 'poor'. That may be the most precise description that can be or should be published about this building. The rest of this document is an effort to assign numerical values to this degradation, with mixed results. If the description 'good' to 'poor' is adequate for your needs, perhaps now would be a good time to quit reading.

How to Measure BEL

There are two methods of measuring Building Entry Loss (BEL). One is what I will call the traditional method which might be called BEL_T. The other is to use an app available on many Smart Phones, which I will call BEL_{CP}. The basic concept in measuring BEL_T is to set up a transmitter and antenna outside the building, a receiver and antenna inside the building, measure the power density outside, measure power density inside, take the ratio, and convert to dB. This sort of equipment has been widely manufactured and used for at least 70 years, so there is a good selection available on the used market. I was able to buy the necessary outdoor equipment, some locally and some on Ebay, for less than $1,000. For the outside I acquired an HP 8620A oscillator, an HP 86222B preamplifier, a Comtech PST 30 W amplifier, and a ETS-Lindgren Model 3115 Double-Ridged Guide Antenna with gain of 9.7 dBi (gain compared to an isotropic antenna) at 2 GHz.

The receiver I chose to use is the GigaHertz Solutions HF38B, which is made in Germany, and costs about $500. It is shown in Fig. 1. It comes with a nice log periodic antenna that is capable of receiving the main cell phone frequencies for the generations through 4G. This is a directional antenna, which adds another level of complexity, particularly for inside measurements with substantial amounts of multipaths. I chose to replace it with a non directional stub antenna, shown mounted on the meter in Fig. 1. There is still a directional effect depending on whether the body of the meter is upstream or downstream of the signals arriving from a transmitting station, so I had to keep the meter orientation constant while collecting data.

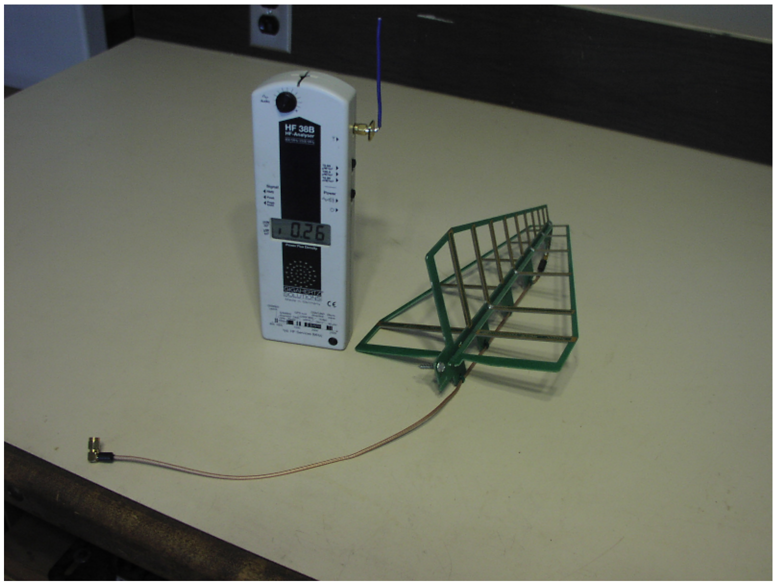

Figure 1: HF38B with log periodic antenna

Measuring BEL_{CP} is obviously much simpler than measuring BEL_T. One just borrows a friends Smart Phone which has the app, reads the displayed value on the screen outside and inside the building, and takes the difference between the two readings. The Smart Phone displays an absolute power level with the units of dBm (decibels above one milliwatt). The difference between the two readings would still be in dB. That is, if the power level outside was -85 dBm and the power level inside was -97 dBm, then BEL_{CP} would be -12 dB.

So why would anyone go to the extra trouble and expense to measure BEL_T? One reason might be to compare local results with those reported in the published literature. All the papers I found on the Internet reported only BEL_T, most written before this Smart Phone app became widely available. In fact, I was unable to find any comparison between the two techniques. It was as though the other technique just did not exist to the authors of the various papers. One important difference between the techniques is that the signal for BEL_T hits the building from only one side, while the signal for BEL_{CP} hits the building from all four sides and the roof. This suggests that BEL_T will be larger than BEL_{CP}. Indeed, my measurements showed BEL_T to be in the range of 40 to 50 dB for the Morton Building, while BEL_{CP} was more in the range of 20 to 25 dB. This is a *big* difference! Let me explore at least one reason the measured values for Building Entry Loss may be expected to vary widely for this particular type of building.

The tacit assumption behind all the loss measurements is that we are measuring a *traveling* wave (as opposed to a *standing* wave). A traveling wave is always moving forward at the speed of light. A standing wave is the combination of a traveling wave and its reflection moving in the opposite direction. They are discussed under the heading of transmission lines, usually included in the first course on electromagnetic theory taught to electrical engineering juniors. I taught this course perhaps 20 times while teaching at Kansas State University. I soon learned that my students needed 5 weeks of class time to absorb enough concepts to be proficient in this area, so whatever else we were discussing, we stopped it and started talking about transmission lines with 5 weeks to go in the semester. Some concepts are non intuitive while others are counter intuitive. I think every electrical engineer you know will agree with the statement that transmission lines and standing waves are as difficult as it gets in the EE curriculum. I obviously do not have the time to bring every reader of this document up to where my students were at the end of the semester, but I will do what I can.

Consider a wood frame house located a mile or more from a cell tower. The cell signal at the house is a part of a sphere, which we approximate by a plane wave (just because the math is a little easier). We say that the incident power density S_1 is uniform over the entire front of the house. I take my HF38B and read the same value (say 10 μW/m^2) everywhere in the front yard. Most of the signal flows straight through the front wall. If the fraction happened to be 90%, then I would read 9 μW/m^2 everywhere inside the house. Most of the remaining signal flows straight through the back wall. I would expect to read at least 8 μW/m^2 directly behind the house, increasing as I move away from the house to where the wave is being replenished by neighboring energy flowing around and over the house.

There are standing wave effects but traveling waves dominate. The power density does not vary too much from one point to another inside the house. We take an average of power densities inside, and divide by the power density outside to get the building entry loss.

Now consider a microwave oven. It has an internal transmitter operating at 2450 MHz, a frequency very close to one of those used by your cell phone. You may notice some interference from your oven to your cell phone if the oven sealing is not at its best. A very high power density leaves the transmitter and is virtually 100% reflected by the first conducting surface. The signal bounces from all six surfaces and sets up a standing wave pattern inside the oven. The power density will be high some places and quite low in others. Oven manufacturers compensate for this by putting a rotating plate in the bottom of the oven. The idea is that all parts of a dish get to spend equal times in the high and low power density areas so everything gets heated properly. You may notice this standing wave pattern if you put a rectangular baking dish in the oven which is unable to rotate.

The standing wave pattern is drastically altered by placing a cup of water in the oven. Power will flow from transmitter to cup regardless of where the cup is placed.

The Morton Building is a double-wall Faraday Cage, basically a microwave oven without a transmitter. Signals do not flow 'through' the walls like with a wood frame house. Incident fields will induce currents near seams and joints, which will radiate into the interior space. This is called 'near fields' as opposed to the 'far fields' assumed with our wood frame house. This topic is strictly graduate school level in electrical engineering.

The energy radiated into the Morton interior will be mostly absorbed inside the building, rather than being reradiated into the back yard. Absorbing will be into water inside the building (note that we humans are mostly water!), into the concrete floor and soil moisture under the concrete, and into any other absorbing materials inside the building. My presence changes the field values I am trying to measure.

What I am trying to say is that a Morton Building poses a different class of electromagnetic problem than the one formed by a wood frame house. A microwave oven is a different beast from a conventional house. Different theoretical concepts are required. Different measurement equipment might be necessary. Taking the average over a larger quantity of data might not get us to a more meaningful result. I have used traditional methods to find both BEL_T and BEL_{CP} for this building.

Traditional BEL

So what sorts of numbers should we expect to measure? I have measured power densities over 1000 μW/m^2 on Main Street in Canon City, Colorado, where an ATT cell tower was located about a block away. But at my house in Canon City and at my office/lab in Rockvale, the outdoor power density is less than 10 μW/m^2 and the indoor power density is less than 1 μW/m^2. A part of my Rockvale property is a gulch that is shielded on three sides by a mesa about 400 feet higher. The power density at the bottom of the gulch appears to be lower than the lowest possible reading on my HF38B, which is 0.01 μW/m^2. The difference in signal level from 1000 to 0.01 is a factor of 100,000 or 50 dB. A factor of 1,000,000 would be 60 dB, a factor of 10,000,000 would be 70 dB, etc. (A Smart Phone will function over an even wider range than that.) Either way of describing the signal levels is perfectly correct, but the custom in the industry is to use dB, rather than keep track of all the zeros.

The older wood frame houses without metalized layers on the window glass or the insulation would have the lowest (worst for the EHS person) BEL_T of perhaps -5 to -10 dB. A modern house with low-e window glass and metalized insulation might have a BEL_T of perhaps -20 to -30 dB. A commercial concrete/steel building with low-e glass can easily exceed -40 dB. This is the case with the Morton Building, which exceeds -50 dB under some circumstances. This means that I cannot measure the BEL of my Morton Building using just the ambient cell phone signals. As mentioned earlier, the ambient signal is less than 10 $\mu W/m^2$. To measure 50 dB, I would need a meter that would read better than 0.0001 $\mu W/m^2$ but my meter reads power density only down to 0.01 $\mu W/m^2$. Meters with the necessary sensitivity would be big, awkward to use, and cost well over $10,000 so I chose to use my own local transmitter to increase the incident power density substantially. This seems to be a standard approach, based on my literature search.

The Comtech amplifier is limited to the frequency range of 1.7 to 2.3 GHz, so I somewhat arbitrarily selected the center frequency of 2 GHz.

I should confess that operating a transmitter at this frequency is illegal without an appropriate license. I hold an Extra Class Amateur Radio license KØHGJ, so if I had adjusted the oscillator to 2.3 GHz, a ham band, I would have been legal. Non amateurs could use 2.45 GHz, the frequency used by microwave ovens, and legal for all of us. It would not help my legal defense, but I always pointed the transmitting antenna toward the side of the mountain and away from civilization.

There does not seem to be a standard protocol for measuring the traditional building attenuation. One person will mount a transmitter on a van and set it at multiple locations around the building under test. Another person will put the transmitter *inside* the building and measure the resulting fields outside. One study will measure attenuation at 0.088, 0.217, 0.698, 2.410, and 5.760 GHz. Another study will look at 5, 12, 25.5, and 32 GHz. One will look at the effect of angle of incidence, where the incident wave is not striking the building perpendicular to the wall. Another will look at the effect of the angle of elevation, where a helicopter is used to beam the signal in from above.

So what is a good measurement protocol to use? This would be expected to change with the type of construction. Some studies suggest that BEL_T decreases with frequency from a few MHz to about 2 GHz, then increases with frequency. Therefore a measurement of BEL_T at 2 GHz could be considered conservative. If my building had a BEL_t of -40 dB for a 2G cell phone, then it would be very likely to have a BEL_T of at least -45 or -50 dB at the higher 5G frequencies.

The first step of my protocol was to calibrate the HF38B. I mounted the HF38B on a 10' tall PVC pipe and placed the transmitting antenna at a similar height but about

20' away, in an open area. The antenna is directional enough that the HF38B would see very little signal reflected from the ground or surrounding structures. I then applied a wide variety of input power levels to the antenna and recorded the HF38B readings.

I then moved the antenna to several locations around the outside of the Morton Building, always at a distance of 10'. The power densities measured at 20' would be multiplied by a factor of 4 to get the presumed power density that would be present at the building (if the building was not present). This is the reference power density S_1.

I built a free standing wood support for the HF38B that holds the meter at about eye level. I placed marking tape on the slab inside the building at 31 positions (omitting the position inside the small storage room) at even spacings so the meter could be moved to all 31 positions and be located at the same place in the room each time. Like a microwave oven, the placement of a container of water (i.e. a human body) drastically changes the standing wave pattern. I would place the HF38B on its support at a given location, step back a meter or so in a consistent pattern and wait for the displayed reading to stabilize. I would stand as still as possible. The reading would usually stabilize after 20-30 seconds. I would then write the value of μW/m^2 on a clip board, and move the support to the next mark on the floor. The average over the 31 positions would be the measured power density S_2. Replication at a given position would not always be good, but the average over the 31 positions would typically be within 1 dB or so.

I measured four different locations for the transmitting antenna: pointed at the closed walk door with no separate screen door, same location but with a closed screen door, then pointed at a window on a side of the building without a door, and finally at a blank wall. The results for the four locations were -41.75, -45.85, -47.84, and -53.17 dB.

I had specified steel doors for the building, but did not think to also specify a steel frame for the door, so what I got was a wood frame. Steel frames are more expensive and therefore less common. A wood frame is transparent to cell signals, so basically there is a gap all the way around the door, perhaps an inch or so wide, that allows cell signals to leak into the building. Replacing a door complete with frame is a nontrivial task, certain to degrade the appearance of the building, so I have decided to leave it as it was built. Any future buildings will have a steel door with steel frame, of course.

Once I realized the problem, I decided to build a screen door over the walk door. A standard storm door fits *inside* the frame, such that it would not cover the effective gap of the door frame. The walk door is a nominal 3' by 6'8" size, so I built a screen door approximately 4' by 6'11" to cover the walk door and its frame. I used 1" by 8" cedar boards and stapled a section of 4' wide aluminum screen to it. The cedar matches the tan color of the building nicely. The plan is to never paint it. The addition of the screen door improved the BEL_T by about 4 dB.

Windows in the shop are standard double glazed and low-e windows. This particular style has half the window fixed in place and the other half movable. The movable portion came with a plastic screen mounted to keep the bugs out. I bought aluminum screen at Home Depot and replaced the plastic screen. Then I bought kits at Home Depot and more aluminum screen and fabricated a larger screen that completely covered the window, and mounted it to the metal trim around the window. The movable half of the window could still be opened and closed. Half the window has two layers of aluminum screen while the other half has only one layer. The window is physically smaller (less area) than the door and the screen is more tightly attached to the metal of the building than the screen in the screen door, so it would make sense for the BEL_T to be better while the external signal source is directed toward the window rather than toward the door. Indeed the results suggest an improvement of about 2 dB.

Directing the signal against a smooth portion of the exterior wall, with no openings at all, shows a further improvement of about another 5 dB. This suggests the ultimate performance of this type of construction. If the building was built without windows and the door was improved, then we might see a whole building BEL_T on the order of -53 dB, or a reduction in signal strength from outside to inside by a factor of 200,000. I personally like plenty of windows to provide lighting levels adequate for most tasks in the daytime without turning on the ceiling lights. It appears that with a little improvement in the door, the BEL_T should be at least -40 dB, a reduction in signal strength by a factor of 10,000. I am hopeful that such a reduction is more than would actually be necessary for most sensitives, so that there is little need to make heroic efforts to improve the building performance. If a BEL_T of -40 dB is adequate for improved health, then there is little incentive to spend possibly large sums to improve this number by a few dB.

But the researcher in me is curious about the possibility of increasing performance with modest increases in cost. As mentioned earlier any followup building will have a steel frame around the door. The window screen would be better if it were copper, or maybe even stainless steel. The extra cost should at least be checked before the next building is built.

I should comment about tabulating results to four significant digits (-53.17 dB, for example). This is not uncommon in published studies on BEL_T but suggests a higher degree of ability to measure BEL_T than is really possible. In my case the only difference in the four measured values was the physical location of the transmitting antenna. The same scale of the HF38B was used throughout. Cables were not connected and disconnected. The position of the gain control knob on the HP 8620A was not touched.

But if I were to repeat the sequence of 31 measurements that were averaged to get figure of -53.17, I might get values that vary by up to 1 dB. The HF38B meter itself is only guaranteed to ±6 dB so even with the very best experimental technique on my part there is always the possibility that my claim of -53 dB is wrong by as much as 6 dB. The *true* value could be as low as -47 dB or as high as -59 dB.

A really honest conclusion of this series of measurements is that I believe that the BEL_T of this version of a Morton Building is better than -40 dB and quite possibly better than -45 dB. This building will need to be occupied by a number of sensitives to see if this BEL_T is adequate for improved health.

Cell Phone BEL

A major problem in measuring BEL_{CP} is that the signal strength provided by the cell tower varies substantially over short periods of time, at least in this particular location. There is also a concern about how the phone is held. The water in the human hand will absorb part of the incoming signal, so varying the grip between tight and loose could conceivably change the results. The receiving antenna inside the cell phone is somewhat directional so changing the orientation between horizontal and vertical will also change the results. I chose the following protocol in an attempt to deal with these issues: I found a 1" by 2" by 2' long piece of wood (a surveyors stake) and glued a perpendicular piece of plywood (about the size of the phone) to one end. I attached the phone to the plywood with two rubber bands. I grabbed the other end of the stake and held it in front of me at eye level. I would take readings with my body facing north, then rotate to west, then south, and then east for equal amounts of time. The phone would always be approximately vertical and the effects of my body and the phone antenna pattern would be averaged out. I then mounted a small Canon video camera on the stake close to my hand with rubber bands. I would turn the camera on and record the information on the phone screen for 15 seconds in each direction. For readout I used the program Kdenlive on an old laptop with the Ubuntu operating system. I would write down the field strength in dBm, then hit Shift—Right Arrow twice to move two seconds forward in the video and write down the next field strength, repeating until the one minute long video was finished.

Over the period of 10/10/18 to 1/9/19 I collected 13 such datasets outside of the Morton Building, with the results given in Table 1. Video 161 is for my son's LG phone, Model LGL44VL. Video 162 is for my grandson's ASUS phone. The remainder are for my ZTE Citrine LTE Model Z716BL. All phones use 4G Android 5.1.1. The menu paths to find the dBm reading are different on all three phones. My phone finds dBm under Status. The LG phone finds it under Network (as I recall) and the ASUS phone finds it under SIMM Card. We cannot make any sweeping generalizations from this

video	average	maximum	minimum
125	-88.44	-94	-83
126	-89.75	-94	-84
136	-87.69	-91	-85
137	-90.28	-99	-83
148	-92.50	-95	-86
153	-80.78	-95	-75
156	-86.75	-90	-83
158	-91.31	-95	-87
161	-94.44	-99	-88
162	-88.69	-90	-87
165	-95.03	-101	-90
168	-88.44	-93	-83
179	-89.69	-94	-75
ave	89.52		

Table 2: Field Strength Readings Outside of Morton Building, in dBm

tiny sample, but at least for these three phones the readings are reasonably consistent. Except for video 153, all the outside average measurements are within about ±5 dB of -90 dBm. I doubt that taking another one hundred videos would change that observation by enough to make it worth the trouble.

The Morton Building is built on the side of a mesa with a commanding view of the Arkansas River Valley to the north and east. There is a good view of Pike's Peak, about 32 miles away and about 10^o east of true north. Cheyenne Mountain, near Colorado Springs and where many TV towers are located, is about another 10^o east of true north. We can receive about 20 over the air TV stations at this location. The city lights of Pueblo, about 30 miles away, are visible on clear nights. In other words we have line-of-sight to dozens of cell towers, but none extremely close. In my case, I can tolerate the field strengths shown in Table 2 without significant ill effects, and have no major problem being outside for hours at a time.

One research goal for this project is to determine the Building Entry Loss for a Morton Building with metal siding on the inside walls and ceiling, both as supplied by Morton and with a few simple and inexpensive modifications such as metal screens on the windows and perhaps a screen door over each outside door (as opposed to a modern storm door). Another goal is to determine if the interior fields can be further reduced by adding absorbing materials inside the interior walls. One of the best absorbing materials, of course, is water, the substance that makes microwave ovens work. It is certainly cheap and readily available. It does have some issues, however, i.e. how does one contain it in something that is very unlikely to leak for the expected life cycle of a house (hopefully a century or more)? We have to consider freeze-thaw cycles and mechanical damage like nail holes for hanging pictures.

Another material that is a possibility is steel mill slag, the material left after a steel mill has recovered all the economically available steel from its product stream. This can be used as aggregate for concrete and would be a definite possibility for experimental houses built with exterior concrete walls and metal roofs. The aggregate is used for road base and is quite inexpensive ($4.25/ton at the plant in Pueblo). I decided to put the slag into a interior wall. I was concerned about the strength of drywall as wall covering so I used tongue-and-groove knotty aspen. One side of the wall was finished aspen to the ceiling and the other side was finished just to above the top of the doors. The slag was carried into the building by bucket and dumped into the opening between the two by four framing to the top of the doors. Then the open side was finished to the ceiling. It took about 5000 pounds to fill about 23 feet of linear wall (a 28 feet long wall less two 30" interior knotty pine doors.

The perpendicular wall to finish out two tack rooms for a shop (or two bedrooms for a house) was also made of knotty aspen but was left empty. I am going to leave the aspen surfaces unfinished (no paint or polyurethane). The Morton Building will have an absolute minimum of man-made chemicals, just powder coated steel siding walls and ceiling, plain concrete floor (no concrete additives), and natural wood. The slag is very inert, provides thermal mass, and hopefully attenuates cell phone signals inside the building. There is a concrete countertop around a kitchen type stainless steel sink which has sealer and epoxy on it that hopefully will be tolerable to most of us.

The average field strengths inside the shop are shown in Table 3. Column 1 is for fields measured before the slag was installed and Column 2 is the field strengths with slag. Other permutations with door and window screening are shown with asterisks.

Videos 160-172 are for the inside with all slag installed, with an average of -117.85 dBm. Videos 173-185 are for the same slag plus temporary aluminum screen installed on the *insides* of all seven windows, attached to the metal trim with clamps and magnets. The average field strength for these videos is also exactly -117.85 dBm. The standard Morton windows have a relatively deep sill, perhaps 8 inches wide and convenient for placing plants and decorations. Adding interior window screens would make this very awkward, and thereby reduce the function and attractiveness of the Morton Building if used as a house. There seems to be no benefit at all, so I think we can drop interior window screens as an option to further reduce interior fields.

The field strength for videos 160-185, with all slag installed, is -117.85, while the strength with no or half slag installed (videos 124-159) is -112.88, a change of about -5

video	dBm w/o slag	video	dBm w/ slag
124	-111.31	160	-119.03
133	-110.53	163	-119.26
134	-111.03	164	-119.28
135	-112.31	166	-114.06
139	-111.31	167	-115.75
149*	-115.50	169	-120.90
150*	-113.09	170	-116.28
151	-114.75	171	-117.25
152	-114.09	172	-118.81
154	-113.53	173***	-118.78
155	-112.28	176***	-115.19
157**	-113.72	177***	-119.22
159**	-113.94	178***	-110.62
		180*** *	-118.44
		181*** *	-122.22
		182*** *	-116.03
		183***	-117.28
		184***	-118.91
		185***	-121.78
ave	-112.88		-117.85
		186*	-104.09
		187*	-98.38
		188*	-112.84
		189*	-120.09
		190*	-117.62
ave			-110.60

Table 3: Field Strength Readings inside of Morton Building. *screen door open. **half of slag installed. ***temporary screens inside of all windows.

dB. The corresponding BEL_{CP} is -28.33 dB and -23.36 dB. This improvement in BEL of about 5 dB is less than I had hoped for, but still suggests that it may be of enough benefit to be worthwhile to those of us who are electrically sensitive.

I mentioned earlier that a microwave oven has a standing wave pattern inside where the signal level can change rapidly over short distances. My measurement protocol through video 185 tended to blurr all this when I stood in one spot and rotated around to four different positions for 15 seconds each. The cell phone was two feet past the end of my extended arm, hence could easily move 2 or 3 inches during each 15 second interval. I decided to put the stake with cell phone and camera on a wood support such that it would be precisely fixed in space for the entire 60 seconds. I would start the camera, step away 10-12 feet, then come back at the end of 60 seconds to turn the camera off. I did this for five different videos, 186-190, at five different positions inside the building, as rapidly as possible. It appeared to be a period where the outdoor field strength was nearly constant. The cell phone had 29 readings of -104 dBm and 3 readings of -105 dBm on video 186, for example. There were three different values for video 187, two for video 188, and four each for videos 189 and 190. The average for the five videos, -116.34 is close to the average of -117.85 dBm of videos 160-185. But we see a 12 dB swing within the five videos, so we definitely have hot spots and dead spots inside the building.

I estimated earlier that the traditional BEL_T is better than -40 dB and possibly better than -45 dB (without slag). Yet, with my cell phone, I measured a BEL_{CP} of -23.36 dB, a difference of 20 dB, or a factor of 100 in power density. It is like we measured 1 W/m^2 with one meter and 100 W/m^2 with another meter. The reader should be asking questions about now. 'What is going on? Why such a vast difference between what appears to be similar quantities?' I do not have anything like a final answer to these questions. I reviewed the literature on BEL and could not find a case where the person measuring BEL_T seemed to be aware of using a cell phone to measure dBm. Likewise I could not find a case where a person using a cell phone mentioned the possibility of using the traditional method.

I was unable to find any technical information about how dBm was actually measured internally. I suspect many of these details are proprietary. On my small sample, I did not see anything to suggest any sort of significant problem with the cell phones. My 'feel' is that both the meters and the cell phones are working 'correctly'. If I am right, then we may need to do some more thinking about what Building Entry Loss means and how it should be measured.

One main difference between BEL_T and BEL_{CP} is that one has a single antenna near the building while the other is immersed in a sea of cell signals. Any building has a number of openings (doors, windows, cracks, etc.) where cell signals can 'leak' into a building from the outside. There are rules about reciprocity where if a signal can leak *in*, it can also leak *out*. We might think about our building as a sieve or a bucket full of holes. The traditional measurement of BEL is like putting a garden hose into this leaky bucket, turning it on, and measuring the water level. The signal level/water pressure is ten or a hundred times that of any other signal trying to get into the building, hence it dominates the situation. With this dominance, we are able to get consistent/repeatable readings of inside versus outside water pressure. The pressure is high enough that the neighbors are being sprayed through every crack.

We still have the same leaky bucket for a building when we are trying to measure a cell phone BEL. But we do not have the high signal level/pressure available to raise the water level to where all leaks are outward. Signals leak in at some cracks and out at others to maintain some particular level. Videos 149, 150, 180, 181, and 182 are for the case where the screen door (mentioned in the previous section about BEL_T) is left open. The average for these five videos is about 2 dB lower than the average of comparable videos with the screen door closed. This suggests that the cell phone signals are leaking *into* the building through the roof and maybe the windows and leaking *out* around the door. When we close the screen door, some leakage out of the building is prevented, so the average power density inside the building *increases*. It is difficult or impossible to notice such counterintuitive situations when making traditional measurements.

Spot checks suggest the interior field strength decreases perhaps 2 dB on the concrete floor and increases perhaps 2 dB near the ceiling. This is consistent with the idea that signals are leaking into the building through the roof and are being absorbed by the concrete floor and soil underneath the floor.