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Save Energy

Stainless Steel Buildings Combat Climate Change

Since the chromium oxide layer that naturally develops on the surface of stainless steel is thin and invisible is a near-perfect solar and thermal reflector. This translates to both and energy savings in hot as well as cold climates, and a reduction in the heat island effect, therefore mitigating climate change.

In the battle to reduce the effect urban environments have on climate change, stainless steel promises an extraordinary contribution as more buildings are built with this material. Since a stainless steel surface is very efficient in reflecting beams of solar radiation without converting their wavelengths, the vast majority of this light energy will shoot back into space without remaining present in the Earth's atmosphere. A stainless steel roof, for example, is even more efficient at achieving this result than a grass covered field of the same size. Should we advance to the point that cities contain a significant coverage area of stainless steel roofs, society can offset the effect of its necessity to burn fossil fuels. While we embrace the idea of continued research in all fields of study regarding climate change, stainless steel can make a massive contribution to the cause at a much lower economic cost than alternative energy methods as they are currently practiced.

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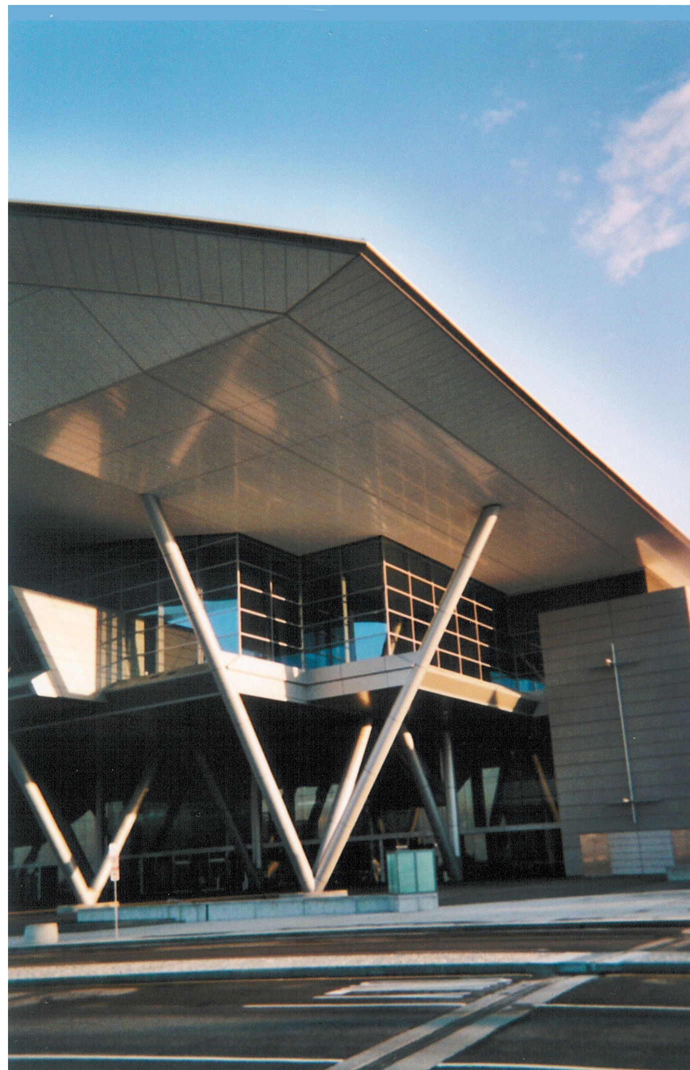
Solar Energy, Global Warming, Heat Islands, Cool Roofs & SRI

The greatest environmental concern of this century is global warming. The physics of the topic is really quite simple, but the politicization of the problem has led many to try to make it obscure. Many stand to gain or lose depending on which solutions to the problem are taken. So there is some obscuring of the comparative value of solutions and this has crept into architecture.

Let's look at the physics first. The sun's radiant energy is the uncontrollable given in the problem. The radiation has peak energy of roughly 1375 watts per square meter which strikes the earth's atmosphere. It doesn't all reach the earth's surface. It is diminished by absorption and reflection. The atmosphere, and principally clouds, reflects 25% back into space. The atmosphere absorbs another 23%. This absorption is selective with ozone strongly absorbing ultra-violet wavelengths, and carbon dioxide and water strongly absorbing infrared wavelengths. This leaves just 52% to hit the earth's surface. Of this amount 90% is absorbed and 10% is reflected back to space. The amount of energy per unit area hitting the earth's surface is called irradiance, and for the US the monthly average is 4-6 kWh/day/ square meter or about 200 watts/m2. When solar energy is reflected the wavelengths do not change, so the radiation which is reflected goes right through the atmosphere to space since it consists of wavelengths that are less affected by atmospheric absorption. The absorbed energy heats the earth's surface. The re-radiation of this heat is at infrared wavelengths. When it radiates from the earth toward space it is almost entirely absorbed by the greenhouse gasses, water and carbon dioxide. To the extent the concentration of these gasses increases, the earth's heat has a harder time escaping and the surface temperature must rise to compensate. This is global warming. This is the problem.



What is the solution? There are several. We can't change the sun's radiation so we have generally chosen to try to manipulate the level of the one significant and controllable green house gas, which is carbon dioxide. The by now obvious ways to do that are to decrease our use of carbon intensive fuels, starting with coal. Each kilowatt hour of energy we generate from wind, hydro, nuclear or hydro means a kilogram of coal not burned and therefore 3.8 kilograms of carbon dioxide not released. This would require, however, the investment of a huge amount of money in these alternative energy sources, the cheapest of which incrementally is wind power at $3000 per kilowatt. That's one solution.

Another solution is sending more energy back into space by absorbing less at the earth's surface. The earth doesn't care how we cool it. The earth's surface has about the average reflectivity of asphalt parking lot or a black rubber roof, i.e., 85 to 90% absorption. When we replace grass (75% absorption) with an asphalt parking lot or road we double the energy absorbed. When we use a stainless steel roof instead of a black one we decrease the solar energy absorbed from 225 watts per square meter to 25 watts per square meter. Avoiding warming by absorption of solar radiation, or conversely expressed, the blockage of the exit of earth's radiation are equivalent. Global warming has been calculated by NASA to be the result of 0.6 watt/m2 excess solar energy, arising from 120 ppm excess carbon dioxide over climate-equilibrium levels. One kilowatt of energy from the sun reflected into space decreases global warming the same as replacing one kWh of fossil fuel burning with wind power. This amount of power requires burning one kg of coal and generates 3.7 kg of CO_2. This is not obvious but the excess CO_2 of 60 ppm over preindustrial levels is that which would be generated from 1.5 TW of energy by fossil fuel. This approximates the amount of electricity consumed in the world in the last 100 years, as it should. Replacing carbon is obviously needed, but is it alone enough?

Replacing 10% of our world's electricity generation with wind power, which is the most competitive non-fossil energy source, except for nuclear, which has been politically excluded in certain parts of the world, requires 2,000,000 MW of new wind farm capacity per year. This is about ten times the total windmill capacity now existing. Clearly this is not a short term solution. It is not clear if it is an affordable solution. At $3/watt capital cost, this requires $3 trillion per year and the total world GDP is only $60 trillion. We need to do more than invest in alternative energy sources, because we can't afford that solution alone.

Reflecting solar radiation is a viable complement to alternative energy sources. We need to build new buildings. Let's make them part of the solution. Let's make them more energy efficient. We are already doing that from the aspect of energy consumption. We are just beginning to understand the energy savings potential of stainless steel. However, the astounding passive reflection of stainless steel is a powerful tool against global warming.

Buildings are the most significant place where architects can alter global warming. A black roof has a 10% reflectance. A new white roof or a reflective metal has a 90% reflectance. Shingles and dark colors are bad. Incidentally and unfortunately, this is where "Cool Roofs" have misled to a degree. Cool Roofs were conceived to combat the heat island effect. This is "neighborhood heating" occurring because of the use of highly solar energy absorbing materials for roofs, e.g. black rubber, tar, dark shingles, dark painted or galvanized steel and aluminum. These materials absorb solar radiation, become hot and transfer it to the local environment by convection. Some have contended that the best solution to this problem is to manipulate the emissivity of the roofing materials so that they transfer more heat by radiation compared to convection to keep the surface air cooler. The problem with that is that such infrared radiation doesn't go far. It just dumps into the greenhouse gas cycle and stays in the local atmosphere. It simply spreads the heating into a larger neighborhood.

The accepted measure of solar reflectance quality of a roofing material is SRI, solar reflectance index. It differs very little from ordinary reflectance. Because of the preceding analysis on "Cool Roofs" SRI placed too much value on emissivity, whereas pure solar reflectance is probably a better criterion. Nonetheless the SRI formula is dominated by the solar reflectance factor, so it does no harm. The simple fact is that the less energy absorbed by a roof, and therefore the more reflected, represents the value of the material to global warming, as well as the local environment. Reflected solar radiation escapes to space. Absorbed solar radiation causes global warming. Reflected solar energy reduces global warming.

Architects can change the world by making better choices in surfaces, and these choices are much less expensive than alternative energy.

Sustainability of Surfaces

We have shown that stainless steel and other high reflectance, low emissivity materials, have surface properties which repel solar warming of both the structure they cover and the world itself. In addition, by virtue of the same surface properties they minimize energy losses to and from the structure by acting as a radiant barrier. This is a level of perfection for which it is difficult to find comparison. They prevent global warming and heat islands, while minimizing energy usage. How can one improve on that?

Durability of Surfaces

Arguably the most obvious benefit of stainless steel among the numerous high SRI products for building exteriors is its imperviousness to the environment. The great enemy of metals is corrosion. The metals historically which resist corrosion are the most prized: gold, silver and platinum. With rare exceptions these are not affordable building materials. When aluminum was first popularized it had great promise, but its corrosion resistance is inadequate for architecture without coatings. The same is true for steel, zinc and copper which corrode readily, but their corroded appearances find some admirers. Lead is used for the same reason despite its being toxic, weak and dense. Only stainless steel and titanium are both resistant to corrosion in any environment in which humans can live. They thus stand out as the two viable bare metals which can keep their initial surface qualities indefinitely.

Why is corrosion resistance so important? When metals oxidize, i.e. corrode, their surfaces take on the physical properties of the oxide. Oxides have low reflectance and high emissivity. Thus, as metals corrode, their initial superior performance, in terms of SRI, degrades. This can happen quickly. Steel rusts in hours, copper oxidizes in days, aluminum in months. The first stainless steel used in buildings has been there for nearly 100 years with no sign of degradation. Non-metallic materials have their own problems with aging. Coatings are organic chemicals. They are degraded by light (UV, primarily), temperature, abrasion, and chemicals in the environment. These are aggregated in the term weathering. When materials weather, their SRI and appearances change, and not for the better. That is the reason initial SRI values must be accompanied by field tested SRI values after at least three years of weathering.

SRI weathering data have been published on over 1400 commercial coatings. Selected results are in the table below.

The aged stainless data point is not three year weathering; it is 10 year, taken from the 140,000 square meter roof of the David L Lawrence Convention Center in Pittsburgh. It is clear that even the very best coatings degrade, by an average of 5% over three years. There is no reason to expect that to decelerate. Thus, for a building with a 30 year lifespan a degradation of 50% cannot be ruled out; indeed it should be expected for coatings. Stainless steel changes only as much as the dirt that lands on it and isn't removed by wind and rain.

The insulation savings of high SRI materials can't be justifiably credited to a material which only saves insulation initially, so an architect must be wary of judging materials.

Material	Initial SRI	3 year SRI
#209 white paint	103	102
#418 white paint	111	105
#425 white paint	109	101
#981 white paint	117	110
#982 white paint	108	102
304 stainless InvariMatte®	112	112

All the Same?

Are all stainless steels the same? No. There are many types of stainless steel based on chemical composition and then there are many surface finishes for each. Both of these factors determine the corrosion resistance and the resistance to soiling in service. The most common stainless steel for architecture is type 304. It fully resists corrosion in non-marine climates. In marine climates, 316, which has 2% molybdenum, an expensive ingredient, is used. In even more severe environments 2003 or 2205 may be used. These latter two have more molybdenum and are harder to form into shapes, but have been used successfully in roofs in the extremely inhospitable climate of the Arabian Peninsula. The selection of the correct stainless is important but not difficult for the many available expert sources.

The effect of surface finish is more subtle. Stainless steel is heat-treated to achieve the desired mechanical and physical properties at the manufacturer. After this step the oxide scale from heating must be removed by very strong acids (i.e. pickling), which also dissolve the surface layer removing any places in which the corrosion resistance is lower, which could lead to pitting corrosion and perforation in service. As long as the surface is not removed this corrosion resistance is intact.

Unfortunately, some stainless is abraded after it is manufactured into sheet. This surface finish dates back to the 1930's when it was the only way to make a quasi-uniform finish on stainless steel, since the as-pickled surface is mottled. It tears away the surface. Because it is not subsequently pickled, the corrosion resistance is harmed. The magnitude of this loss is approximately equal to the difference between 304 and 316. This is pretty significant, so it is prudent to not use abraded stainless steel for exteriors of structures.

What's the alternative?

There are some very good ones. Any abraded surface finish can be replicated by rolling the surface with textured rolls. This avoids surface removal and loss of corrosion resistance. Architecturally, a possibly greater benefit is that the surface finish is extremely uniform and reproducible. This is never the case with abrasively-made finishes which continually vary with degradation of the abrasive media.

These rolled textured finishes can replicate abraded or shot blasted finishes without the surface damage, and the can decrease the glare or gloss from a surface without diminishing the reflectance or increasing the emissivity significantly.

Staying Clean

Among the high SRI finishes the ability to stay clean varies a lot. Coatings are organic; so, is most dirt. The polarity of organic molecules attracts other polar molecules. Metals have no polarity because of their dispersed electron cloud bonding. This eliminates one type of soiling for metals and accounts for some of the differences from coatings in terms of soiling.

The second factor is mechanical damage. Metals are much, much harder than any organic coating so particles of dirt cannot embed in stainless when driven by wind and rain. The last factor is trapping. This is controlled by surface configuration on a micro scale. Most coatings are quite smooth, at least initially, so in this regard they are okay.

Maintenance

The roof is often the highest maintenance item on a building, especially it ages. One of the great, unanticipated benefits of the stainless roof on the David L Lawrence Convention center in Pittsburgh (DLCC) is that it has required absolutely no maintenance in its lifetime. It probably never will. In fact, the InvariMatte® finish on this roof is hydrophobic, or self-cleaning. This building just received a Platinum award from LEED® for maintenance and operations. Its management is happy that the roof has never been a source of difficulty. Interestingly, the same 304 stainless with an abraded finish on exterior wall panels has soiled sufficiently that expensive hand cleaning was required for the hosting of the G20 meetings there several years ago.

A Case Study, Pittsburgh

The DLCC is a building highly praised for its green qualities and initially received a Gold LEED® certification. It is however a greater contributor to the environment than it was even intended to be. The 140,000 square meter roof is made of type 304 stainless steel which despite having a low gloss appearance is highly reflective of solar radiation. It reflects 90% of solar radiation into space versus 15% were it the average for US cities. This avoids 190 w/m2 of solar energy and its global warming effect.

One watt of electricity generated by burning coal causes much more, about 25 times more, global warming than one watt absorbed from the sun, because of the persistent effect of carbon dioxide in holding in radiant energy, but even so the reflection of 2.5 megawatts by the DLCC roof provides the same benefits to global warming as a 5000 square meter solar panel array, which would generate 165 kW. An array of that size would cost over $3 million. This is considerably more than the premium paid for the stainless roof, suggesting that public policy does not correctly recognize contributions made by this type of endeavor. It should be rewarded with a tax benefit equal to that enjoyed by other alternative energy efforts.

However, the roof of the DLCC was not intended to be central to its green design. It was specified for energy and maintenance saving. The serendipity of it is that little was known of the exceptional reflectivity of stainless steel when it was designed. It was a risk taken and rewarded. It’s SRI has not measurably changed in ten years and it has required zero maintenance. Because it is stainless steel its life will exceed 100 years.

A New Idea of Green

So, for architects and civic planners, a new concept of green design must take hold. It is not just the energy we conserve by good design. It is the energy we contribute to the earth’s energy balance. SRI must be incorporated into all urban considerations, from parking lots to roofs. The contribution to the solution of this global problem is too great to ignore. Unfortunately, Secretary of Energy, Steven Chu, received yawns when he proposed just this in 2009. To some environmentalists, attacking global warming by means other than CO2 reduction is politically incorrect. However, the problem cannot be solved quickly or economically without the use of more reflective building materials. We already have an effective global warming solution; build with stainless steel.

Conclusion

We hope it is clear to the reader that stainless steel-clad buildings not only save energy, but significantly reduce the heat island effect. We are hopeful that we can encourage further study in these areas. Should you have questions or comments regarding our work, we would be pleased to hear from you.

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