Daylighting- A Global Climate and Economic Perspective

WHY ARE BUILDINGS SO IMPORTANT, AND HOW DOES "COOL DAYLIGHTING" PROVIDE BENEFITS?

A GLOBAL CLIMATE AND LOCAL ECONOMIC PERSPECTIVE

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[Note: while the following material describes the opening presentation by Dr. Aitken at the Wisconsin Daylighting Collaborative workshops, the first portions of the descriptive narrative have been extracted from the transcript of a talk presented by Dr. Aitken in New York City on November 5, 1998, at the Second Annual Symposium for a Solar Future, and published by Global Futures. Both the New York and Wisconsin talks were supported by colored slides. The primary theses appropriate to the Wisconsin presentations have been extracted in the following, rather than just a description of the pictures, with concluding remarks that segue directly into the Wisconsin Daylighting Collaborative workshops.]

A perimeter office in the new daylit national headquarters of the Union of Concerned Scientists, in Cambridge, Mass. Installed lighting power density is 0.44 watts per square foot. Actual measured lighting power has been 0.25 watts per square foot. (Office design and Photo by Donald W. Aitken.)

Introduction

Buildings are incredibly important, beyond the fact that they house us and shelter us and provide spaces within which we work or are entertained or are cared for. But while we appreciate these basic functions at some level, buildings are still terribly underrated. People just ignore buildings beyond seeing them as enclosures.

It is a major task for us to try to awaken an awareness of the importance of our built environment to us and to what we are doing, whether it's the classrooms we're teaching in or the offices we're working in or the conference rooms we're speaking or listening in.

My function in this opening portion of this workshop is to address just some of these areas--the importance of buildings to our energy policy and our economy and to reveal the enormous potential for buildings to help us obtain a cleaner environment. And I shall further focus my remarks on the special significance of daylighting in buildings.

Global climate change is real, and the greatest global environmental threat that we are facing today. It's also the greatest global economic threat that we have ever faced. We can achieve the greatest benefit for the least cost in the shortest time in mitigating climate change if we start with our built environment, both the existing built environment and those buildings that we're designing and which have not yet been built. The following section focuses on this.

The Reality of the Forces of Global Warming

Everything that we do with energy pours stuff into the environment. When we create energy, it pours stuff into the environment. When we use energy, it pours stuff into the environment. In some cases it sticks around locally, and can be seen as smog or measured as ozone. We've done a pretty good job of getting rid of the worst of that. But what we can't see continues to go into the environment, and we now do things on a human scale that's so great that our emissions into the air are altering the composition of the global atmosphere.

We're increasing the carbon dioxide content in the atmosphere. We're increasing the abundance of nitrous oxide in the atmosphere. We're increasing the abundance of methane in the atmosphere. And we're increasing the abundance of stuff that never existed in the atmosphere before, chemicals that are alien to the way that the Earth is used to working, such as FCC's. But these are still just in parts per million in an atmosphere primarily made up of nitrogen, oxygen and argon. So what's the worry?

The Earth is at a very delicate thermal balance. The amount of energy coming in from the sun equals on average the amount of energy that goes out to space by radiation. All of the mechanisms of the Earth that use and distribute energy operated within that balance--or at least until human actions began to change it.

Producing, refining and using energy injects emissions into the atmosphere. The result is a disturbance to the energy flowing through the atmosphere, with a greater effect on the energy reradiated by the Earth.

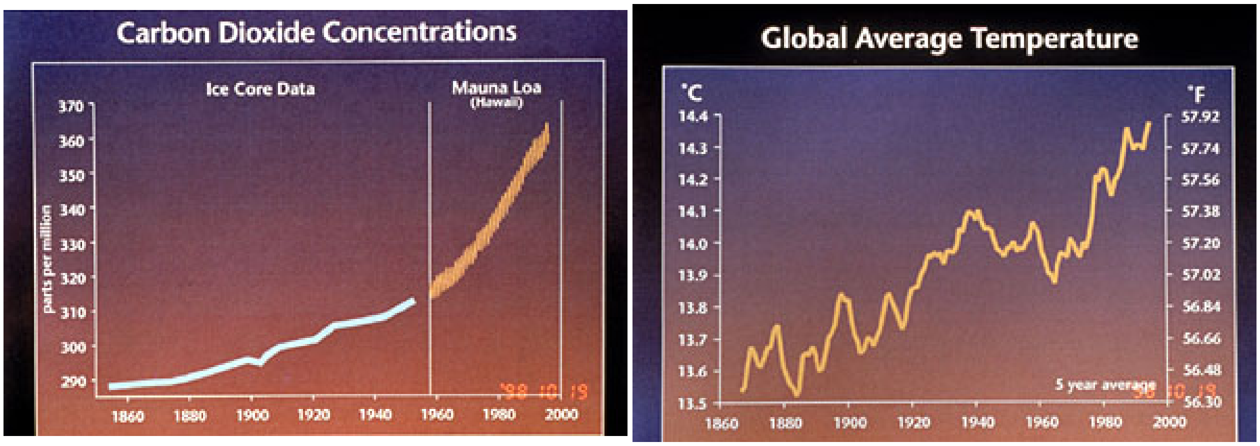
We are changing the energy flow through the earth's atmosphere. We're introducing more aerosols and dust and soot, which affects the flow of solar energy coming to the earth's surface, and we are introducing the greenhouse gases, which have a molecular interaction that reduces the ability of the earth's radiated infrared energy to flow back out from the surface. And it turns out that the impact on the earth's ability to reradiate is larger than the reduction in flow of incoming solar energy. Therefore, we are unbalancing the two sides of the earth's energy-balance equation.

Anything that we do to disrupt the energy flow to and from the earth's surface must disrupt the earth's thermal balance--that's a straight statement of physics, not needing "research" to "prove" it. And since we are changing the flow of energy through the atmosphere in an unbalanced way, it is also a straight physics statement that the Earth must respond. Nobody can argue that point and nobody does. So it places the whole climate change issue as a grand game of global atmospheric roulette. How will the Earth respond? Will we like it? Will it be fun? Will it be good for economies or bad? Unfortunately, everything that we look at suggests it will be devastatingly difficult for human societies and human economies and global ecological systems to accommodate to.

How is the Earth Responding to our Greenhouse Gas Injection?

We have various tools to help us to try and guess how the Earth will respond to our differential reduction of the flow of energy back out to space. One way is to use ice core samples and fossil plant samples to look at the relationship of the temperature of the Earth to the carbon dioxide content in the atmosphere as far back as 160,000 years ago. And we find that over this entire period there has been a very close correlation between carbon dioxide content in the atmosphere and the temperature of the earth's surface. Which drives which? No one really knows and it doesn't matter. But we do know that there is a synergistic response by the Earth's climate to the amount of carbon dioxide in the atmosphere.

We now have a carbon dioxide concentration in our atmosphere that's greater than anything we've seen for the last 160,000 years, and the rate of increase is also the greatest that the Earth has seen in at least 160,000 years. So the first thing we might expect is that by retarding the flow of energy outward the Earth will get warmer, and with rapidity that parallels the rate of injection of carbon dioxide into our atmosphere. And, indeed, we see that there's been a monotonic increase of the temperature of the earth's surface over the last 100 years or so, and the rate of that increase also appears to have picked up significantly in recent years. The hottest year on record was 1997. 1998 was hotter than 1997. So now 1998 is the hottest year on record. And so it is now going, from year to year and even month-to-month.



The increase in the Earth's atmospheric carbon dioxide during the industrial development of the world, and the apparent parallel increase in the temperature of the Earth. Scientists are now almost unanimous in the opinion that this represents a "discernible" impact upon the Earth from human activities. (From "Climate Change, State of Knowledge", Executive Office of the President, Office of Science and Technology Policy, October, 1997.)

So we are seeing evidence that's fully consistent with what we might expect, the evidence of the temperature rising abruptly and fast, faster than at any time in the last 160,000 years in response to carbon dioxide rising faster than at any time in the past 160,000 years. So those circumstances are scientifically consistent and also consistent with our history. The nature of the "debate" (which is no longer a scientifically defensible position) is that one cannot know for sure that this isn't just another statistical "blip" in the earth's temperature history, just coincidentally happening in a way that is consistent with what we would expect from our own meddling with the earth's atmosphere. But 1,500 of the world's leading atmospheric scientists, making up the Intergovernmental Panel on Climate Change, have deduced that there is "discernible" evidence of climatic consequences of human emissions into the air.

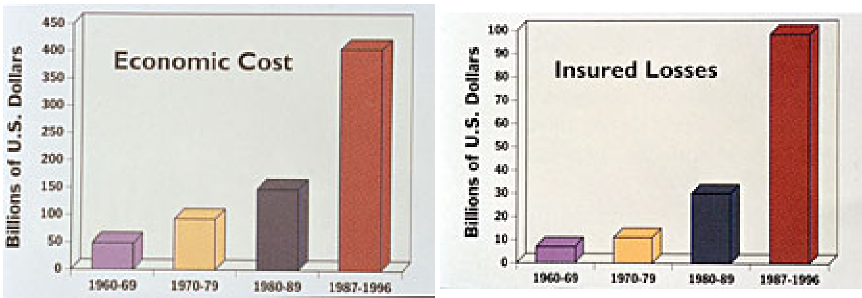
A doubling of the atmospheric content of carbon dioxide is inevitable, even with the most stringent controls and cooperation among nations. But we are also heading toward the likely result of a quadrupling of the atmospheric content of carbon dioxide. That's more carbon dioxide than has been in the atmosphere for at least 60 million years, and we could get there by the middle of the next century, a dot of an eye in terms of Earth time scales.

From Global Warming to Climate Change

It has always been a bit of a mystery, at least to some people (such as critics of the concept of global warming), that with the injection of carbon dioxide so rapid, the temperature response of the Earth's surface, while apparently now increasing, is not nearly so rapid. The reason for that is basically that when we just look for temperature signals we're really looking at the wrong thing.

Climate is the Earth's mechanism for distributing energy and trying to equalize the energy potential across its surface. As we increase the amount of energy remaining near the earth's surface by reducing the earth's ability to radiate it away, the Earth must try to redistribute a greater amount of surface energy, possibly by an increase in violent atmospheric events. And so climate is the area where we really expect and anticipate to first see the consequences of our altering the of the earth's atmosphere, and we think we do now see some changes.

For example, the incidence of rainstorms of two inches or more, which is a flooding rainstorm in the United States, has increased by 20 percent just this century. And the dramatic increase in weather-related insurance claims in the last three decades as a result of the equally dramatic increase in intense climate events has caused the insurance industry of the world to lead the campaign to reduce carbon dioxide injection into the atmosphere. The insurance industry of the world makes its living from risk, and they can no longer tie their future projections to past historical statistics, for everything is now changing and becoming unpredictable. As a result the insurance industry just stops insuring those events, such as hurricanes, which may increase from our actions.



The increasing incidence of major storms in the United States has led to a dramatically increasing burden on both the economy and the insurance companies. (All figures are in constant dollars.)

The increasing economic risk from climate change is being heaped right back onto our own shoulders, without insurance protection. Therefore, as we will bear the economic brunt of whatever happens, the avoidance of that threat is now also on our own shoulders. So where do we start?

Responding to the Economic Challenge of Climate Change--With Building Energy Efficiency

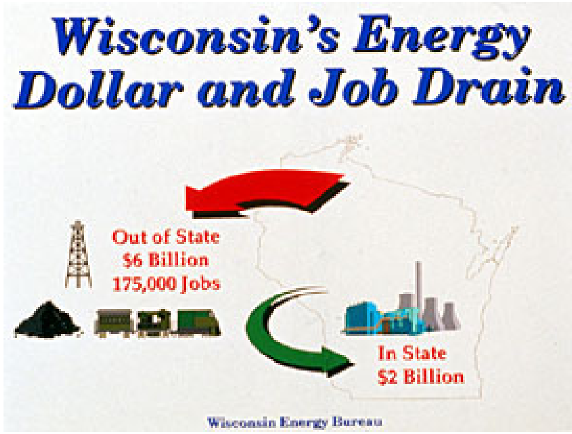
How do we respond to a "threat" with suspected but not fully predictable consequences? And who should be the ones who respond? The world's greenhouse gas emissions are dominated by the developed nations, and the United States is the granddaddy of them all, contributing more greenhouse gases than any other nation of the world. So if we really want to try to help the world, or lead the world in reducing emissions into the atmosphere, the biggest opportunity and challenge is here in our own country. We've got to get our own house in order first. And in this way we can also reduce the danger to our own climate and economy from the developing nations who might otherwise follow a business as usual path, emulating our own global environmental mistakes.

If we're going to get our own house in order where do we start? We start with energy, for the dominant source of greenhouse gas emissions by far is from energy use. I started this talk by saying buildings are incredibly underrated. People pay no attention to buildings. I could just as well have said energy is incredibly underrated. Policy makers pay no attention to energy. They don't pay attention to the impacts of energy, and they seriously mistake the economics of energy and energy policy. Let us try to do better here.

If we look at U.S. energy supply it's no particular surprise to anybody that petroleum, natural gas and coal dominate our energy supplies--the very resources that are causing the emissions into the atmosphere. But the moment we start talking about reducing the use of these marvelously convenient energy resource, people worry about shortages and crises. Many of us remember the gas lines in 1973-'74. We behave very badly in times of shortages.

We did respond to that crisis by beginning to take efficiency seriously, and we did quite well. Nevertheless, we still use twice as much energy per capita in the United States as do the other developed nations. And if people feel that is just because we have a more affluent lifestyle, we should note the economically more serious circumstance that it takes twice as much energy to produce a dollar in the economy of the United States as it does in Japan, in Germany, or in other major global economic competitors.

Analysis of our history reveals that we had enough energy from our own resources to power our own society and our economy until about 1970, after which we no longer had enough to meet our growing energy appetite, so we simply started importing it. And from 1970 to 1980 we became a debtor nation, and by the time we got to 1980 we were spending around $80 billion to import energy resources. That $80 billion, if it were spent for energy resources indigenous in the U.S., would multiply its economic benefits as it folds back through our own economy. This is an enormous loss of economic activity. It isn't just energy that drives the economy. It's also the way we spend our money for that energy, and whether those expenditures help our country or help other countries.



In 1996 Wisconsin spent $8 billion for energy. $6 billion of that was exported from the state's economy, in order to import energy. That represented a loss of support for possibly 175,000 new jobs in the State, as well as loss of economic activity worth perhaps twice the $6 billion. (Courtesy of Steve Clemmer, Senior Energy Analyst, the Union of Concerned Scientists, based on an anlysis performed by him for the Wisconsin Department of Administration.)

For example, it appears that we spend about one-quarter of the national defense budget protecting our access to the Middle East--one-quarter of $250 billion a year, something like $60 billion a year, to protect our access to oil. What does that do to the cost of oil? We import something over 2 billion barrels of oil per year. If we spend $60 billion to protect that right, we're adding two more dollars from the U.S. taxpayers for every dollar they pay for oil, raising the price to us from the oft-quoted world average price of $11-15 per barrel to something over $40 per barrel. Alternatively, oil to the U.S. economy, taking into account the real costs associated with securing its availability, is three times more expensive than it is to other economies. And if we compare those real costs with those of the domestically available alternative energy resources the latter are a lot more economically favorable than we have been led to believe!

What we do instead is to go and look for more oil within our boundaries, even though it may be in environmentally sensitive areas, and we practice what David Brower likes to call the "politics of exhaustion". If we find it we'll extract it as quickly as we can and use it until it's economically exhausted. But an alternative is to go to every house that is heated by oil and which has single glazing and is not weatherized, and replace the windows with double-glazed windows and weatherize the rest of it.

How much oil could we save in the United States by weatherizing our oil-heated homes? It's about equivalent to the Alaskan pipeline, which means we have another Alaskan pipeline of oil resource presently being used to blow heat out of our windows and walls. If we weatherize our buildings, and reduce those losses, then the energy from the oil that was being leaked out can go back into society to be used for economic productivity. It can drive vehicles. It can power industry and commerce, and all of a sudden we've got economic value from it again, with no more environmental impact than we had by burning it to lose heat in houses. That's a hugely important external economic value to weatherizing homes. It puts money back into society. It creates jobs. It supports industry and transportation.

But can we actually power a growing economy with energy efficiency? We have our own history to demonstrate that. Starting with our oil shortage scare in 1973/74 we began to introduce energy efficiencies into our economy. Prior to that time if the economy grew by three percent, our energy use also grew by three percent. But after 1973/74 we went through an important 13-year to 15-year period in which the economy grew about 35%, and our energy use did not grow! We used the cost-savings from efficiency to plow back into other sectors of the economy to promote continued economic expansion. So we proved by our own experience that efficiency can power an expanding economy.

A side benefit of this is that, if we had not gone through that energy efficiency period, our energy costs today would be about $150 billion per year more than they are now--$150 billion per year for what we found to be energy waste, with no economic value! Aren't we lucky to have that $150 billion per year available for greater economic productivity today? And that was accomplished by introducing barely more than 2% per year of improvements in the efficiency of our use of energy. But if we squeezed the amount of energy out of each dollar that Japan and Germany do, for example, we could save another $220 billion per year, in addition to the $150 billion per year we are already saving, and still have all of the energy services that are near and dear to our hearts--and essential for our economy.

We also managed to reduce our electricity use by about $50 billion a year during that same period. Buildings use two-thirds of all of the electricity in the United States. So this is further proof of some of the benefits of our energy efficiency in buildings folding right back into society.

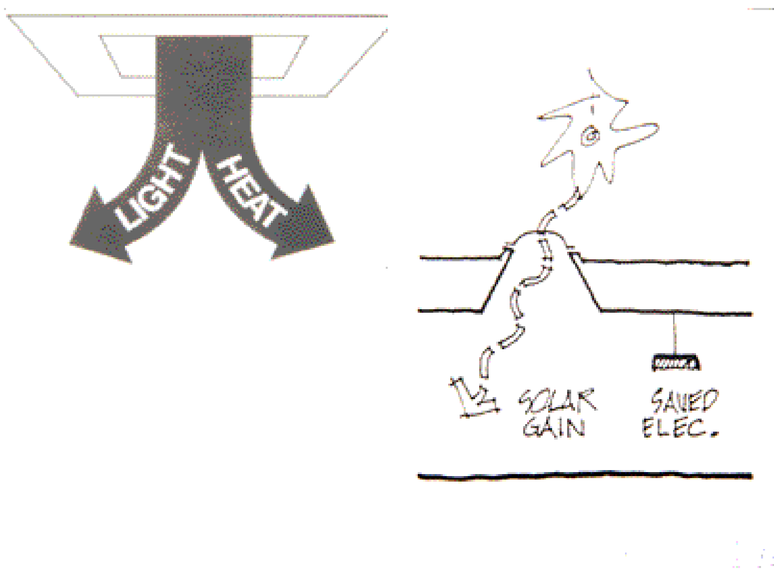
Part of the problem with energy efficiency and with renewables, of course, is the higher first cost. But if you go out and pay more for a compact fluorescent lamp, it will outlive a whole bunch of incandescent lamps, and in the process it's probably a far better investment than anything you have got--better than any CD's, any stocks, any bonds, so investing in energy-efficient appliances is the best place you can put your money as a starting point (unless you do indeed have investments that return more than 25% to 50% per year). And in creating the same amount of light for every incandescent bulb that you

replace with a compact fluorescent, 400 pounds of coal and, therefore, the emissions from 400 pounds of coal, is avoided. So, in this view, we have many opportunities to mitigate climate change threats and to enhance our economy all at the same time. And buildings are the most accessible and least-expensive starting point for all of this with the biggest bang for the invested energy efficiency dollar.

Daylighting in Buildings as an Economic Strategy--if Done Right!

The largest use of primary energy in the U.S. is to produce light for buildings! Even when viewed from the more misleading point of view of energy end-use in buildings, energy for the direct (light) and indirect (heat and, therefore, air conditioning) use in buildings can, on a gross average, account for better than half of the energy use in buildings. The irony, though, is that what we call "lights" in buildings are in actuality extremely efficient "furnaces", yielding most of their energy as heat, and relatively little as light. I am always astonished when I am, for example, talking to Arizona architects and builders, and I must ask them why they put all of those furnaces in the ceilings and then install large air conditioners to mitigate the impact of those ceiling-mounted furnaces.

The alternative, of course, is yet another aspect of what we call "bioclimatic architecture". That means to stand on the building site and look for all of the environmental resources that might naturally provide for light, comfort and efficiency, and then to design our building to capitalize on those opportunities. Daylight is the most obvious resource that is available in all climates. There is certainly an economic message in the use of daylight, for lighting energy is far and away the greatest cost of light in buildings. I always wonder why building owners quibble about the cost of the bulb ("lamp", in lighting professional language), when the cost to replace a cheap short-lived bulb is over twice the cost of the bulb itself, and when the cost of the electricity to run it is many, many times the first cost. An energy efficient lamp saves its own extra cost many times over, and is always an economic bargain.



The predominant energy emitted by even the most efficient lights is in the form of heat, which represents a significant share of the load on the mechanical cooling system. Replacing that light with daylight must be done very carefully, though, to provide a net cooling benefit. When this is properly done, the resulting downsizing of the cooling system provides an important reduction in the first cost of the building.

But everyone knows that daylight brings in solar heat at the same time. How can that be "cooler" than electric lighting? It is partly because of the unusual sensitivity and adaptability of the human eye. Only about 1/2 of one percent of the full brightness of sunlight still equals about 50 foot-candles on a work area, which is more than ample for most uses in buildings. So with proper architecture over 99% of the sun’s heat can be rejected, while still yielding 100% of the light needed inside of a building. But if the architect does not pay attention to this, then daylighting can bring in unwanted heat and offset its inherent energy efficiency value.

The second benefit of daylight is physically intrinsic to the light itself: daylight delivers more light ("lumens") per unit of heat transmitted through the window ("Btu") than the equivalent ratio of the best fluorescent lights on the market. For example, 100,000 lumens of light produced by incandescent bulbs would require almost two "tons" of air-conditioning energy to extract the heat simultaneously produced. This could be reduced to less than 2/3 of a ton of air-conditioning if fluorescent lights are used instead. But 100,000 lumens of daylight deliver heat that only about º ton of air-conditioning needs to extract, or less than one-half of the heat from the best fluorescent lights on the market.

"Cool Daylighting"

As a consequence of the inherent benefits discussed above, we can define what architect and instructor Steve Ternoey calls "cool daylighting", that is, daylighting delivered in just the amount that is needed to provide for interior illumination, carefully controlled even on the perimeter to avoid over-brightness and annoying visual contrasts and thereby also minimizing the heat load on the cooling systems.

Since we are in Wisconsin, it is interesting to note that Frank Lloyd Wright understood the energy and comfort values of "cool daylight" almost 100 years ago. For example, in his 1903 design for the Larkin Building in Buffalo, New York, Wright provided for daylighting from the sides, ends and top of the building, to give soft, constant and shadow-free illumination everywhere. He also designed in electric lights, which were then the "new" illumination technology, to assure sufficient illumination at all times. But he noted that during the day the electric lights should be off, leaving only natural illumination, to avoid the unnecessary and uncomfortable heating of the building during the day from the artificial resources. Photographs taken of the Larkin building show just that--well-illuminated spaces, with ceiling mounted electric lights all turned off.

Fortunately, when proper lighting and daylighting design are integrated with other environmental concerns, the result is a *more* attractive and *more* comfortable office environment, which enhances productivity, thereby multiplying by many times the economic benefits of the energy savings alone. Examples are now out in the literature actually documenting increased productivity and enhanced overall cost savings from daylighting in offices and retail establishments, and better performance of children in daylit schools.

The case for daylighting is therefore made: it provides for reduced environmental impact from energy production and use and for enhanced economic productivity locally and nationally. But the techniques for designing "cool daylighting" are not necessarily intuitively obvious. The purpose of the Wisconsin daylighting workshops is to demonstrate the techniques, in order to assure that Wisconsin reaps the economic benefits.

Perimeter offices in the Larkin Building in Buffalo, New York, designed by Frank Lloyd Wright in 1903. This was the first sealed and mechanically cooled office building in the United States, and established Wright's reputation on the international scene. Wright didn't have the benefit of today's glare-control glazings, so he resorted to architectural techniques to provide for usable daylight. The outer surface windows to the left are placed high, to reduce visual glare and to allow reflected light to "wash" the ceiling, thereby helping the daylight to penetrate farther into the room. The interior openings to the right are into the atrium, with reduced daylight intensity, so Wright compensated with larger openings. The electric lights are turned off during the day, according to Wright in order to avoid unnecessary heating of the space when daylight is available. This was a statement made 106 years ago of the design philosophy that still serves today as the basis for the 1999 Wisconsin Daylighting Collaborative Workshops. (Copyright the Frank Lloyd Wright Foundation. Photo used by permission.)

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