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BUILDING ECOLOGY: RELATION OF BUILDINGS TO ENVIRONMENTAL and SOCIETAL ISSUES

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Introduction

In the 1960s, commercial buildings became more isolated from the outdoor environment and were built and filled increasingly with synthetic materials. In the 1970s, concern for energy conservation drove ventilation rates down, and indoor air quality and climate problems proliferated. In the 1980s, we learned that we had to address thermal comfort, indoor air quality, and energy management in an integrated fashion. When satellite observations helped scientists confirm the seasonal appearance of the ozone hole over the Antarctic region, it became even more evident that, as the ecologists have said for decades, 'everything is connected to everything.' The corollary is: 'you can't do just one thing.'

Growing awareness of the sensitivity of the environment to human activity by today's global population accelerated efforts to address environmental issues around the world. In Europe, it is easier to come by awareness of resource and land limitations and the ability of the environment to absorb pollution; Europeans have lived with "limits to growth" for centuries. America developed with a frontier mentality - there is always more land, more mineral resources, more energy, and more space. If we can't do it here, we will just expand, we even do it in outer space.

Now limitations are beginning to confront us - the Montreal Protocol calling for control of ozone-depleting chemicals and Agenda 21 emerging from the United Nations Earth Summit in Rio de Janeiro are the most visible international political signs. Yet the political dialogue on sustainability is limited. After all, sustainability is about the long term, and politics is inherently short term in its focus.

Even so, throughout the world, and especially in developing nations, there is a groundswell of activity around "sustainable development." The Netherlands has adopted a National Action Plan, and there are currently efforts underway in 30 European countries to develop and apply national plans for sustainability. Scientists and economists alike are increasingly incorporated sustainability concepts into their work, and they have produced some alarming results. What all these efforts have in common is that they all show the need, some - say it is an urgent one - to begin reducing consumption, pollution, and encroachment by 40 to 80 percent or more in the next ten to 25 years. In the case of fossil fuel energy consumption, the required reduction is above 90 percent. Questions of distribution of wealth among the have and have-not nations will press upon us as the lesser developed countries begin to demand "western-style" consumption and produce the concomitant environmental impacts. The resources are not there, and the planet cannot absorb the effects.

1. GLOBAL RESOURCES CANNOT SUSTAIN CURRENT LEVELS OF ENERGY OR RAW MATERIALS CONSUMPTION.

Current resource consumption, globally, projected 50 years into the future with equivalent per capita consumption would result in a dramatic impact on the environment.

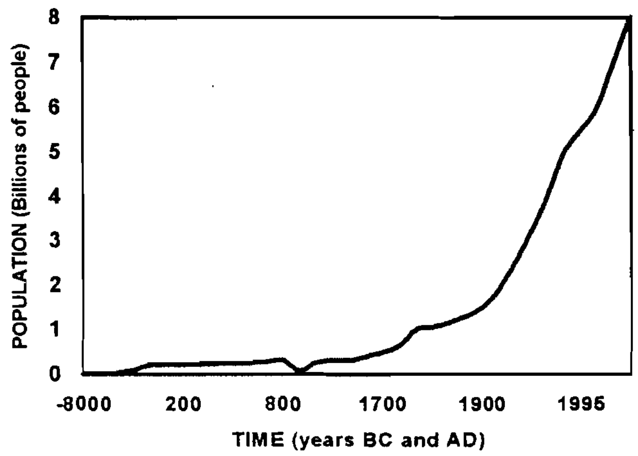

Figure 1. J-shaped curve of exponential population growth. (Miller, 1995)

2. CURRENT POLLUTION GROWTH PATTERNS ARE NOT SUSTAINABLE.

The projected population growth (without any assumed increase in current per capita levels of consumption) and the associated pollution will result in environmental impacts far beyond the ability of the global environment to respond, according to our current understanding.

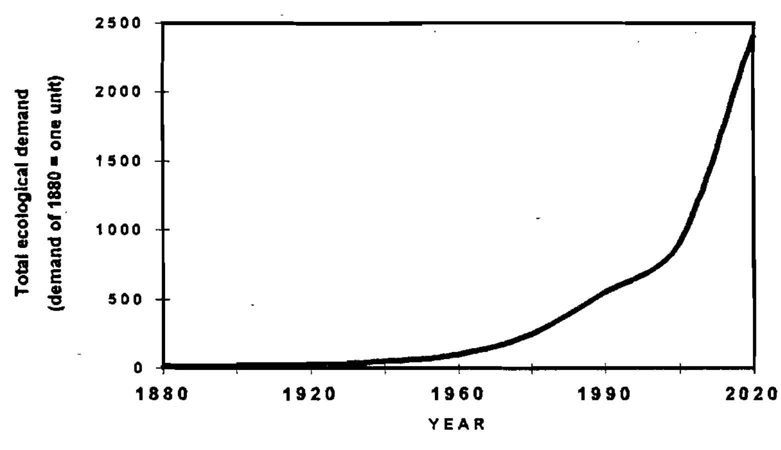

Figure 2. J-shaped exponential curve of environmental impact (Miller, 1995)

3. BUILDINGS ARE MAJOR RESOURCE CONSUMERS AND ENVIRONMENTAL POLLUTERS.

Pollution produced by buildings and the energy and raw material resources they consume (for construction and operation) are major factors in the sustainability of the quality of life we currently enjoy and to which most developing nations aspire.

Buildings are responsible for significant fractions of all resource consumption, pollution production, and open land encroachment. This is true both globally and nationally in the US.

a. U.S. buildings consume 10% of all energy used in the world. (U.S. building-related energy use is more than 40% of total energy use, and the U.S. uses 25% of global energy use.)

b. Global resource consumption for building construction is 40% of all resource consumption (Worldwatch Institute paper for detailed estimates)..

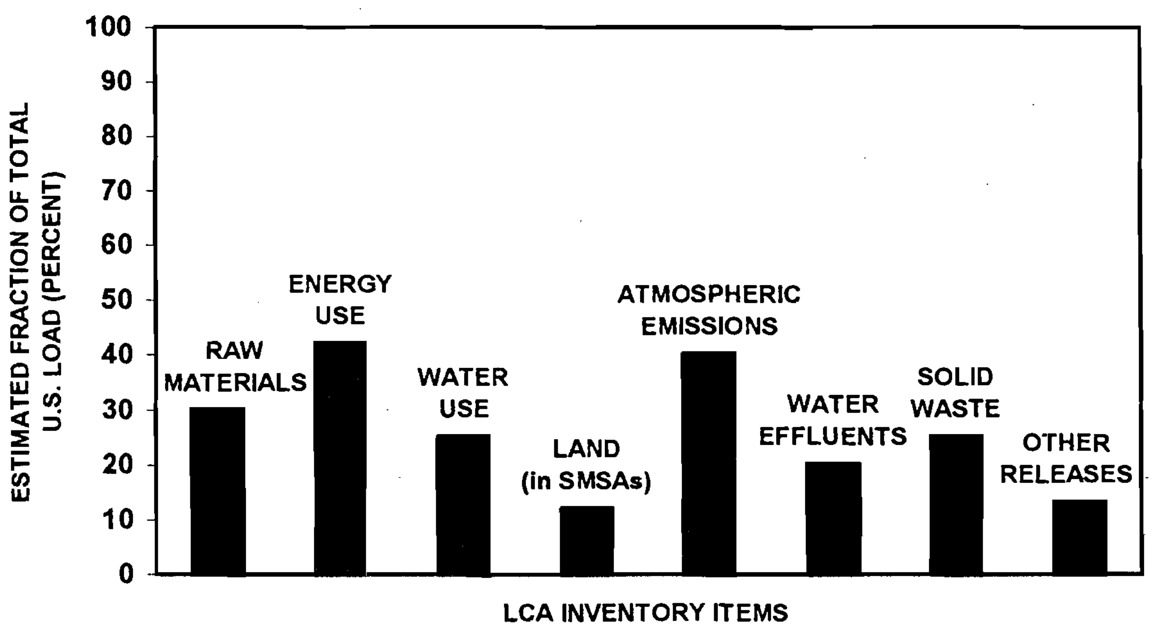

Figure 3. U.S. Buildings' share of total environmental burden (Levin et al, 1995)

c. Building-related material consumption is more than 25% of material consumption. For some resources such as, clay, sand, and timber, buildings consume half or more of all available natural resources. More than a quarter of all copper, aluminum, steel and polystyrene consumption is for building-related uses. And fully three-quarters of all PVC consumption is for building-related uses in the U.S.

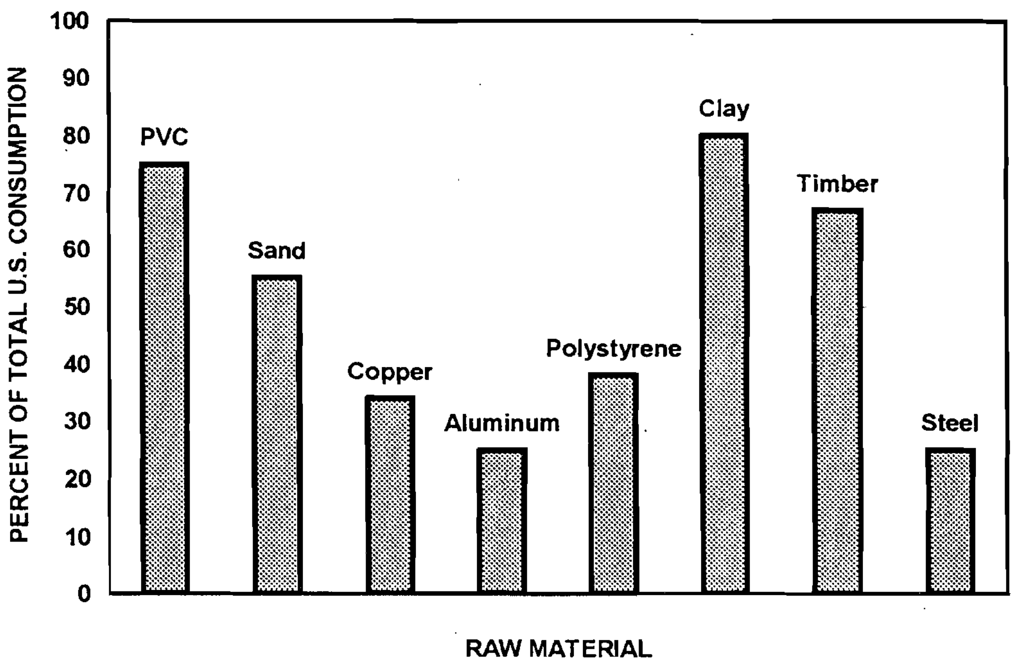

Figure 4. Building-Related Raw Material Consumption as Percent of Total U.S. Consumption

4. "SUSTAINABLE BUILDING" CLAIMS TO DATE ARE UNFOUNDED

Efforts completed to date to guide design and construction have been based on a limited understanding of the environmental problems and have not reflected a systematic approach to evaluating design/construction/operation trade-offs.

Guidelines and other publications have shared an abundance of worthy environmental concerns and goals. The two best known and most articulated are the Building Research Establishment Environmental Assessment Method (BREEAM) from the Building Research Establishment in Garston, Watford, the UK, and Building Environmental Performance Assessment Criteria (BEPAC) from the School of Architecture, University of British Columbia in Vancouver. Although they each present a standardized process and a set of criteria, neither is based on a systematic analysis of building environmental impacts and an explicit valuation as the basis for evaluating designs. By default, various environmental problems are treated equally. A unit of air pollution is equal to a unit of global warming or ozone depletion. Therefore, the basis for assessing designs, although they have used a point system to encourage keeping track of environmental performance, does not address the problem of design trade-offs.

This important deficiency is not unique to these building environmental evaluation tools; most life cycle analysis tools and methods have also dodged the difficult question of weighting various environmental impacts. This is due, in part, to the fact that such weighting requires recognition that any weighting scheme reflects a set of societal values. In government, there is a resistance to adopting an explicit set of weights although the use of a discount rate (federally mandated) reflects a higher value on the present than on the future. Without weighting different environmental problems, there is no way to assess the trade-offs between strategies that may conserve energy versus other resources, strategies that minimize ozone depletion versus those the protect endangered species or scarce mineral resources, etc. Design is a process of evaluating alternatives and making trade-offs.

There are some things we cannot afford to trade away; these include the stratospheric ozone layer, global climate, and biological diversity. The earth may not be able to recover from damage to the ozone layer or significant change in global climate. An extinct species or a severe depletion of the gene pool of any species is also not recoverable Other environmental problems, more localized either in time or space, can be remediated or mitigated. Local air and water pollution can be addresses in a reasonable number of years if the commitment is made. Loss of topsoil or deterioration of its quality can be reversed in a few years time if the commitment is made. Acidification or eutrophication of waters can be reversed. But once species are lost or the global climate changes significantly or the ozone layer depleting chemicals are released, reversal is either impossible or extremely long term.

The weighting or "valuation" phase of a life-cycle assessment or environmental sustainability analysis requires resolution of questions of social justice, generational justice, and genetic justice (NASH, 1994). Distribution of resources and pollution between the "haves" and "have-nots," whether within or among nations, is a fundamental social question that is going to become more pressing as resources become more scarce and pollution problems exacerbated. Trade-offs between present benefits and future costs are questions among generations, most of them as yet unborn. And trade-offs between humans and other species are already bitterly contested as seen in the on-going conflict over the spotted owl habitat and the northwest forests they inhabit.

5. PRELIMINARY WORK ON EVALUATION TOOLS FOR SUSTAINABLE BUILDINGS HAS BEEN COMPLETED IN EUROPE AND AMERICA.

Recently-initiated efforts in the U.S. and Europe have outlined the components of a comprehensive approach to sustainable buildings, and the principals have begun to articulate the principles and to diagram and describe the necessary analysis. However, both of the two major efforts are currently unfunded after completing initial start-up phases. The work required to complete these efforts is substantial and will require a significant commitment of resources from government or industry.

A comprehensive model has been designed in the US by a National Institute for Standards and Technology (NIST) and has been developed by a NIST-EPA team (of which the present author is a part). The recent political climate and its Congressional consequences have resulted in the premature suspension of progress on this project. Currently the team is in the "final" phase of its work without immediate prospects for further funding to continue model development. Related work will continue under Department of Defense funding, but it will not include development of the analytical tools

In the Netherlands, W+E Consultants International, (in Gouda, NL) with funding from the national electric utility (Novem), has also designed a model. But there, too, funding has not continued and the model, Eco-Quantum, awaits funding further development. These models both are built on the basis of life cycle principles and are intended to provide guidance in the selection of building materials and, ultimately, in the design of buildings.

Figure 5 shows the analytical framework for both models.

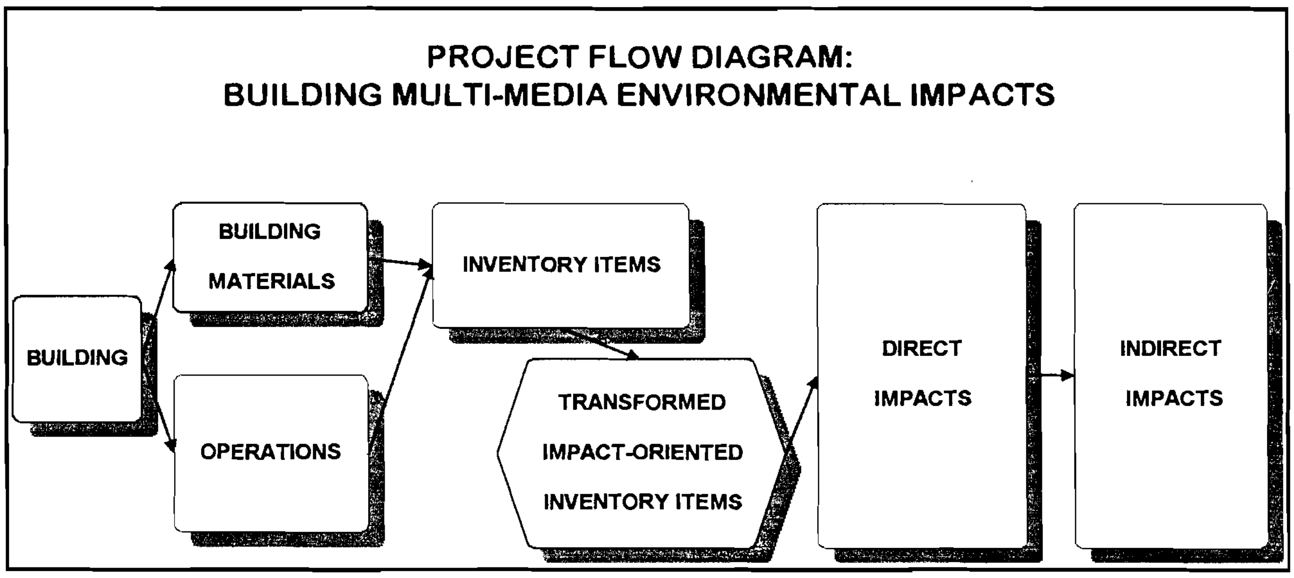

Figure 5. Framework for analysis of building life-cycle impacts

6. DATA PROBLEMS ARE LARGE BUT SURMOUNTABLE

All efforts to assess the sustainability of building products as well as of whole buildings depend on the availability of substantial data needed for life cycle assessment inventory.

These data are currently not consistently available and not much is forthcoming in the US. In Europe there are a number of databases that are generally available and growing.

There are many difficulties attached to data acquisition. Data become quickly outdated presenting significant challenges to those dependent on accurate and reliable data for their analyses. It is often difficult to separate plant inventory data into the portions attributable to individual products where more than one product is manufactured at a single plant. Plant-by-plant variations exist within companies in resource consumption, specific raw material sources, energy supplies, and pollution emissions for a single product.

7. THE BUILDING SECTOR OPPORTUNITIES TO IMPACT GLOBAL SUSTAINABILITY ARE EXTREMELY LARGE.

Because buildings' share of total resource consumption and pollution is so large, the design, construction, operation, and maintenance of buildings present significant opportunities for reduction in environmental problems. Since building energy consumption relates closely to two of the most important environmental problems, global warming and ozone depletion, there are very great opportunities for buildings to make a difference.

8. SUFFICIENT KNOWLEDGE AND TECHNOLOGY EXIST FOR IMMEDIATE, DRASTIC IMPROVEMENT IN THE ENVIRONMENTAL PERFORMANCE OF BUILDINGS.

It is said that knowledge exists to reduce building energy consumption by a factor of five to ten. This is partly due to the fact that where energy is costly, or for other reasons, there have significant advances made in building design, materials, equipment, and in environmental control systems during the past two decades. In Europe, where energy costs have been higher than those in the U.S., roughly half or less energy is consumed in buildings on a per square foot basis while maintaining high quality environments. Even in the United States, many buildings exist that use one-third or less of the energy used in typical buildings for similar occupancies.

Shifting away from ozone-depleting chemicals for use as refrigerants in building equipment and blowing agents in foam insulation products has already begun to occur on a very large scale. Further reductions in emissions can be accomplished through proper operation and maintenance of equipment in-place containing the ozone-depleting chemicals.

9. ENVIRONMENTAL PERFORMANCE FREQUENTLY CORRELATES DIRECTLY WITH ECONOMIC PERFORMANCE.
Pollution prevention pays for itself. It is estimated to be 4 times more efficient to prevent pollution than to clean it up after it occurs.

Example 1. NOx emissions abatement on the two large boilers at PG&E's Moss Landing Power Plant (2nd largest fossil fuel fired power plant in the country) cost 1/4 as much (capital costs) by installing improved burners that produced less NOx than it was to cost to remove NOx by the use of ammonia in an SCR device. The risks inherent in the use of ammonia and its cost are additional downsides of the "end of the pipe" approach.

Example 2. Using low-emitting materials in buildings results in a lower indoor air pollution load and allows the use of less ventilation. This translates directly into lower capital costs as well as lower operating costs to maintain a given level of indoor air quality.

Example 3. Efficient lighting devices replace Inefficient lighting fixtures that produce excess heat thus requiring more cooling capacity and ventilation system operating costs. Energy efficient lighting fixtures have been found to pay for themselves quickly. Daylighting is even more cost effective, eliminating completely the waste heat production of even the efficient lighting fixtures. Significant energy and cost savings are achievable in both residential and commercial buildings.

10. INDOOR AND AMBIENT ENVIRONMENTAL QUALITY ARE OFTEN ACHIEVED THROUGH THE SAME MEANS.

Durable materials are good for the indoor environment and for the general environment.

a. They last longer, require less frequent disposal and replacement.
b. They require less cleaning and maintenance chemicals that pollute the indoor air.
c. They reduce maintenance and replacement requirements, producing economic gains for building owners and operators.

11. MAJOR ENVIRONMENTAL PROBLEMS MUST BE IDENTIFIED AND PRIORITIES SET AND FOLLOWED.

We have gone through a rigorous process of identifying and prioritizing environmental problems based on the major published work on the subject.

Table 1. Criteria for priority ranking of building related environmental problems based on parameters used by EPA's Science Advisory Board plus one additional criterion incorporating sink status/capacity.

1. THE SPATIAL SCALE OF THE IMPACT
   Global, regional, local (large scale being worse than small
2. THE SEVERITY OF THE HAZARD
   More toxic substances being of more concern than less toxic substances
3. THE DEGREE OF EXPOSURE
   Well-sequestered substances being of less concern than readily mobilized substances
4. THE PENALTY FOR BEING WRONG
   Longer remediation times being of more concern than shorter times
5. THE STATUS OF THE AFFECTED SINKS
   An already overburdened sink is more critical than a less-burdened-one
   (Sinks = receptors, environmental compartments)

After assessing candidate environmental problems against the criteria in Table 1, we then considered the relative contribution of buildings A large share of building-related in- or out-flows being worse than a small share This resulted in the list in Table 2 below.

Table 2. Prioritized list of environmental problems.

Building Related Environmental Problems

Top priority

1. Habitat destruction / deterioration (directly resulting in Biodiversity loss)
2. Global warming
3. Stratospheric ozone depletion

High priority

- Soil erosion
- Depletion of freshwater resources
- Acid deposition
- Urban air pollution / smog
- Surface water pollution
- Soil and groundwater pollution
- Depletion of mineral reserves (esp. oil and some metals)

We examined environmental problems in terms of total future consequences versus total current consequences. This enabled consideration of the effect of not acting to address a problem immediately. That analysis resulted in a clear distinction between the top priority problems and the remainder. The top three problems involve consequences that are very large and, although somewhat distant in time, they are either irreversible or extremely difficult and slow to remediate. Therefore, we concluded that the top priority problems cannot be compromised in any sustainable scenario.

In addition to the ten environmental problems listed in Table 2, the EPA's Science Advisory Board also listed human health problems related to environmental exposures. We have listed those that are building related in Table 3 below.

Table 3. Building Related Human Health Problems

Building occupants
Indoor air pollution - radon
Indoor air pollution - nonradon
Accidents in buildings (electrical, fire, falls, etc.)
Building workers
Building construction / demolition / material manufacturing etc.

12. VALUES ARE THE BASIS FOR PRIORITIZING ENVIRONMENTAL PROBLEMS

Any effort to prioritize environmental problems involves human values. Whether consideration of these values is explicit or not, people's values play an important role There are some environmental values that are generally accepted according to Tom Graedel of AT&T. Graedel says there are four points that "everyone" agrees on. These are the following::

1. Preserve human species
2. Enhance quality of life
3. Preserve diversity of life
4. Preserve aesthetic qualities of earth.

13. AD HOC GUIDANCE BASED ON EXISTING KNOWLEDGE FOR SUSTAINABLE BUILDING.

Based on the priorities outlined above, we have developed a preliminary set of suggested measures organized according to the environmental problem categories. These suggestions are based on past experience and are intended to provide guidance for actions that will address the environmental problems. Some of these suggested measures are more practical or more easily implemented than others. In any case, they are presented here simply to show that using the environmental problems and their rank ordering as a starting place, policy-makers, designers, and facility managers, can set some objectives and establish some practices to improve environmental performance based on a rational, systematic analysis.

Table 4. Prioritized Measures to Reduce Environmental Impacts of Buildings

Ecological problem	**Suggested Measures for Minimization of the Buildings' Environmental Impacts**
(in order of importance)	*(more or less in order of importance)*
1. Habitat Deterioration & Destruction (leading to direct Biodiversity Loss)	1. Avoid the use of tropical woods. 2. Do not use wood from old growth forests. 3. Do not use wood from clearcut forest practices. 4. Build on already-cultivated or developed land instead of clearing yet undisturbed (natural) land for the building site. 5. Reuse existing buildings. 6. Keep the buildings' "footprint" as small as possible. 7. Apply reused or recycled building materials. 8. Keep direct or indirect fossil use as low as reasonably possible, (for example by selecting wood from relative nearby forestries). 9. Prefer non-wood construction materials whose raw materials (sand, copper ore, etc.) come from "low biodiversity density areas"(e.g. arid regions, not forests!). 10. Minimize building related solid waste generation. Be efficient with building materials, avoid unnecessary waste.
2. Global Warming	1. Site buildings so that automobile use is discouraged, and biking, walking and use of public transportation is promoted. 2. Keep need for additional heating as low as reasonably possible by incorporating energy conservation principles in the building shell design and construction (insulation, weather-stripping, frugal use of glass surfaces), and by incorporating passive solar principles (e.g., double-glazed windows, most glazing on the south), and by zoning the building and its heating system in warm vs. cold rooms / zones. 3. Cooling: Eliminate/minimize cooling loads through careful design of glazing (size, overhangs, shades, orientation), building structure (mass) , restricted use of artificial lighting, Use natural ventilation where feasible. Use earth coupling where possible to reduce cooling loads in low structures. 4. Lighting: incorporate daylighting as much as possible, use energy-efficient lighting fixtures and lamps, use task lighting instead of general lighting, use occupancy sensors, dimmers, timers, and other technologies to minimize wasteful lighting. 5. Use energy efficient heating elements, e.g., gas powered -(solar is even better) water heaters, space heaters powered by gas (not electricity unless from renewable sources), gas cooking appliances, etc. 6. Integrate active solar, small-scale hydropower, or wind energy systems for on site electricity generation.
3. Ozone Layer Depletion	1. Avoid refrigerants containing CFC's (including HCFC's) in air conditioners and other cooling units or. avoid the need for air-conditioning, see *Global Warming*) 2. Avoid insulation materials from CFC's or HCFC's as blowing agents. 3. Avoid building materials that use Ozone Layer Depleting chemicals during production (e.g., as solvent, or for cleaning or degreasing of metal surfaces or electronic components).

Table 4. Prioritized Measures to Reduce Environmental Impacts of Buildings (continued)

4. Soil Erosion	1. Do not use wood (both tropical and temperate) resulting from clearcut forest practices. 2. Minimize use of metal materials whose ores were obtained by strip-mining practices. 3. Keep the disruption of the building site as low as reasonably possible . Leave trees where they are (as much as possible). Respect natural occurring geology as much as possible. 4. Build next to, or close to an existing road. 5. Incorporate a rainwater collection & drainage system (the land around the house can be an important part) that introduces a time lag between collection of the water and release to the buildings' environment.
5. Acid deposition	1. Minimize the need for additional heating & cooling by incorporating passive solar design principles in the buildings' structure and envelope. 2. Lighting: Use daylight as much as possible; use energy-efficient electric lighting fixtures. 3. Eliminate the use of electricity for water and space-heating uses. Instead, use a gas or (an additional) solar space / water heating system. 4. Use "low NOx, low SO2" burners. 5. Site buildings so that automobile use is discouraged, and biking, walking and use of public transportation is enhanced. 6. Avoid building materials based on hydrochloric acids (or that use HCl during production). 7. Incorporate wind, solar, hydro power energy systems directly on the site.
6. Freshwater Resource Depletion	1. Keep Building Related Electricity use (from the Grid) as low as reasonably possible (See Acid Deposition #1,2,3) 2. Keep water use of toilets as low as reasonably possible; e.g., by using low-flow toilets, or one that enables choice between "large" and "small" flush cycles. 3. Keep water use of bath, shower and sinks as low as possible by incorporating water-saving devices. 4. Incorporate a grey water system in the building. 5. Use building materials that required little water during extraction of its raw materials, production etc.
7. Airborne Toxics / Smog	1. Avoid building materials that require highly toxic air emissions or large quantity VOC releases during their production, manufacturing, installation, maintenance, refinishing, or removal. 2. Use building materials that have relatively low embodied energy content. 3. Use materials that generate relatively little air pollution during mining, manufacturing etc. 4. Site buildings so that automobile use is discouraged, and biking, walking and use of public transportation is promoted. 5. Prefer locally available building materials (=less transport).

Table 4. Prioritized Measures to Reduce Environmental Impacts of Buildings (continued)

8. Surface water Pollution	1. Incorporate devices for on-site recycling of human waste as much as possible; e.g., compost toilets, septic tanks. 2. Choose wood from silvicultures that use no or limited application of herbicides, pesticides. 3. Choose building materials that are relatively "clean" (be careful when selecting metals, for example - due to toxic runoff during mining - and building materials based on chlorine compounds). (Use "LCA-approach") 4. Keep building-related soil erosion as low as reasonably possible *(see Soil Erosion)* (Pollution by sediments). 5. Keep building-related electricity use for heating, cooling, lighting as low as possible (see *Acid Deposition* #1,2,3).(Thermal pollution!).
9. Soil & Groundwater Pollution	1. Avoid underground storage tanks (for petroleum for example). In stead use above ground tanks with water/oil tight emergency reservoir under tank. 2. Favor "less toxic" alternatives when selecting building materials. Pay particular attention to building materials based on metal ores and chlorine compounds, for example. 3. Avoid unnecessary waste of toxic products. Practice separate toxic waste collection at the building site. 4. Use "low-impact" paints, coatings. 5. Minimize building related electricity use (especially when the electricity is provided by a nuclear power plant).
10. Depletion of Fossil Fuel and (Some-Scarce-) Mineral Resources	A) Fossil fuels: 1. Site buildings so that automobile use is discouraged, and biking, walking and use of public transportation is promoted. 2. Minimize building related electricity, gas and petroleum use for heating and cooling by integrating passive solar design principles into the design. 3. Use building materials with a low embodied energy content (in relation to their function!).. 4. Minimize the necessity for artificial lighting by using daylighting AMAP and by using energy efficient lighting fixtures. 5. Avoid electric water heaters. Insulate gas heating devices well, and where possible integrate a solar pre-heater. B) Scarce Metals: 1. Limit the use of metals for non-essential applications like window frames, exterior panels, etc.. (Just use it for more essential applications like wiring, hardware, reinforcing steel.) 2. Use very efficient methods when using metals like copper that are expected to become scarce within one or two decades. For example: use copper wire with a high recycled content. 3. If using metals, favor ores for which there are still some resources available within the US. Example: zinc.