PDH Academy

An Overview of Sustainable Design

AIAPDH243

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Overview of Sustainable Design Final Exam

1. The need for solar control glazing may be reduced if which of the following is explored earlier in the project:
   a. Selection of high-efficiency HVAC systems
   b. Additional wall insulation
   c. Orientation and arrangement of windows in the building in order to limit solar gain
   d. Availability of renewable electricity from the local utility

2. Interior finishes for a sustainable design...
   a. Are unimportant, since they have a short useful life
   b. Should try to minimize VOCs and other potentially harmful off-gassing chemicals
   c. Should always be recycled materials
   d. Should be chosen principally for their durability

3. Choosing a building site in an urban context with available access to public transit
   a. Indirectly supports reduction of automobile travel and emissions
   b. Available transport options and shorter commutes
   c. Lower cost for site development because less parking may be needed
   d. All of the above

4. What is the "tripod" that makes up the Triple Bottom Line?
   a. Health, Safety, Welfare
   b. Bigger, Stronger, Faster
   c. People, Planet, Profit
   d. Firmness, Beauty, Delight

5. Which of the following building components typically has the longest lifespan?
   a. Building control systems
   b. Floor finish materials
   c. Exterior cladding
   d. HVAC systems

6. Commissioning provides what benefit for a building at the beginning of occupancy?
   a. Ensures that the systems are operating as intended
   b. Establishes a future value for the sale of the building
   c. Selects utility providers for services to the building
   d. Surveys the occupants to determine what they like and don't like about the building

7. Which of the following is an example of a positive synergy in design?
   a. Increased efficiency of lighting and other interior equipment means reduced heat load inside building, allowing smaller sized cooling equipment to be selected.
   b. Taller building allows more rentable area.
   c. Selection of building HVAC systems that offer commercial rebates from the utility provider.
   d. Selecting a remote greenfield site for a building to provide more natural green space and better solar availability.

8. Which of the following is a synergy associated with site selection?
   a. Constructing on a brownfield site to obtain grants for site remediation.
   b. Constructing on a formerly wooded lot, and selling the harvested trees for firewood.
   c. Constructing in an urban environment with multiple available transportation options, which allows a smaller required parking area.
   d. Constructing a multi-level parking structure rather than having a parking lot, in order to reduce the project footprint and fit on a smaller piece of land.

9. What is the most important reason for selecting a ground-source heat pump system for a building?
   a. Ground source heat pump does not off gas chemicals which could cause "sick building syndrome" in the building inhabitants
   b. High efficiency system will reduce greenhouse gas emissions
   c. A GSHP demonstrates that the building is cutting edge
   d. There is no difference, because off-site emissions are no different than on-site emissions from a standard gas fired furnace.

10. Energy modeling of a proposed building should be done:
   a. Several times through the course of project design to test options and modify the design.
   b. Only if the project is going to incorporate renewable energy in the design.
   c. After all materials have been selected for the project so that the model can be as accurate as possible.
   d. Before site selection, so that a suitable site can be selected to match the building's needs.

11. Passive design is a beneficial strategy in sustainable design because of all of the following except which:
   a. It can reduce the cost of energy and of powered systems for the building.
   b. It incorporates green space and improves indoor air quality.
   c. It is not dependent on power inputs to function.
   d. It frequently needs less energy and requires less equipment.

12. Water Sense labeling is for:
   a. Identifying products meeting EPA's specifications for water efficiency and performance
   b. Living Building Challenge certification of vegetated roof systems
   c. Identifying superior water resistant exterior materials
   d. Water meters used in regions with drought conditions

13. Externalities are:
    a. Issues that can only be solved by local government intervention
    b. Factors that ultimately effect everyone
    c. Factors outside the designers' control, and therefore don't need to be worried about.
    d. The outermost face of a building cladding system

14. Adaptive reuse is an important sustainability strategy for …
    a. Quickly delivering a project, since the structure already exists.
    b. Maintaining the energy efficiency of the existing building.
    c. Avoiding the presence of Red List materials in a project.
    d. Preserving the embodied energy of an existing building.

15. Durable, long-lasting exterior cladding materials are:
    a. Undesirable, because of their higher cost.
    b. Only appropriate in cold-weather climates.
    c. Preferable for extending the useful life of a building.
    d. Harder to work with, and therefore not suited for sustainable buildings.

16. How does the quality of construction of a building relate to sustainability?
    a. Sustainable features must be traded off as quality and cost are increased.
    b. Quality construction will last longer, which extends the sustainable use of the building.
    c. Sustainable features will function regardless of the overall building quality.
    d. Only the highest quality components qualify as sustainable.

17. What two aspects of sustainability can an ERV (energy recovery ventilation unit) contribute to?
    a. Energy efficiency and stack effect
    b. Ground source heat pump and stack effect
    c. Energy efficiency and indoor air quality
    d. Ground source heat pump and night-time flushing

18. Who is responsible for the building being operated in a sustainable manner?
    a. The building owner and management
    b. The design team
    c. The occupants and users
    d. All of the above

19. Daylighting is...
    a. Preferable where possible, because it has no energy cost and is the highest quality light.
    b. Problematic, because the accompanying solar gain always has to be offset.
    c. Limited in usefulness, because only south-facing windows can use it.
    d. Not controllable, because the sun changes position throughout the year.

20. The Cradle-to-Cradle principle is...
    a. Increased efficiency and performance by using all-new materials
    b. Used to evaluate building energy use
    c. A program to ensure the comfort of interior spaces
    d. Waste from one process serves as feedstock for another process

21. From which of the following lists should materials not be used on a project?
    a. EnergyStar rated equipment
    b. Red List materials
    c. Cradle-to-Cradle certified products
    d. Materials with recycled content

22. Stormwater control is best done:
    a. On the building site, to recharge the underground water table
    b. By quickly moving surface water to nearby storm drains
    c. By preventing water from soaking into the ground
    d. With central processing plants to filter contaminants

An Overview of Sustainable Design

Course Description*:* Sustainability is an important consideration at all stages of a project, but there are different elements that are best considered at different times in the course of the project. This course will be an overview of sustainability concepts, with an emphasis on "when" in the project these aspects should be considered for the most effective application of these principles. We will use the major LEED categories as an organization of the different elements to include: site and infrastructure/water/energy/materials and resources/interior environment.

Part I. Terms and Definitions

Sustainability can be considered as the ability for a material to be available in the future.
The United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

ASTM E2432-19 is a standard that describes the general principles of sustainability with reference to buildings. While the standard is a very general and high-level document, it offers a good rationale for the importance of considering sustainability: "Every building and building product has environmental, economic, and social impacts. These impacts occur at all life-cycle stages in multiple ways and on local, regional, and global scales. It is imperative to understand the nature of these impacts and their relationship to the general principles of sustainability in order to address the opportunities and challenges they present in buildings."

Sustainability is an ideal, and not something that can be achieved perfectly. No condition represents absolute sustainability. Because it is a discussion with respect to a dynamic system, sustainability is a perspective that recognizes a wider web of relationships and needs that go beyond the immediate environment of the project and that works within the constraints of that broader context. It represents a perspective that can be applied to evaluating all decisions involved in the construction and operation of buildings. But these decisions are always involving tradeoffs, and the benefits of each decision have some drawbacks in other areas. Rarely is there an answer that addresses all needs with total equity.

No single feature or system defines sustainability universally. It is a broad concept that ultimately spans the entire breadth of the globe and extends forward far into the future. While it defies any absolute characterization, there are a series of important concepts that are important foundations to understanding sustainability. In an architectural context, sustainability is a set of strategies and principles oriented towards a goal of understanding and minimizing the impacts that stem from the decisions, selections, and actions taken in the context of building design and construction.

Renewable Materials

Materials that are consumed as they are used, without being able to be replenished or replaced, are fundamentally unsustainable. Petroleum products are a clear example of this. Whether burned as a fuel or refined into plastics, the amount of petroleum available decreases as it is used for these purposes. Alternative products and technologies are being developed that can replace non-renewable materials with compatible options that are made from renewable sources. Some plastics, for example, are being produced using vegetable oils, sugars, cellulose, and other feedstocks in place of petroleum.

Renewable resources are those that can be replenished naturally, or which are not depleted by their use. Renewable energy is that generated from wind or solar energy, for example, which will continue, regardless of how much is being harnessed to produce electricity for human use. Renewable materials are capable of being replaced in a practical period of time that will allow for that material to be available in the future. Wood is one example of a material that can be replaced once it is harvested. But, although it can be a sustainable material, not all wood is necessarily a sustainable material. Clear cutting forests harvests the wood as a material but does not do anything to replace the trees that have been removed. Furthermore, the destruction of the forest habitat has widespread and long-term consequences for the land. However, better harvesting and forest management practices allow the production of lumber with fewer environmental impacts.

Not every material that could be renewable is necessarily maintained in that way, however. Renewable materials can be sustainable, in that their present consumption does not necessarily reduce their availability in the future. But overconsumption in the present can lead to the decline of available amounts of that material. If the forests being harvested for lumber, for example, are being logged at a faster rate than the trees are able to grow back, then, eventually, the lumber from that forest will no longer be available. Although wood can be a renewable resource, and trees continue to grow, that does not mean that all use of wood is sustainable or that wood can be freely used without any consideration of the remaining available stock, the manner in which it is being harvested, or how the forests are being maintained and managed. Mismanagement, overuse, and failure to maintain the forests as an ecosystem can also have an impact on the long term prospects of being able to continue to supply wood from those forests.

The Triple Bottom Line; People, Planet, and Profit

Sometimes characterized as a three-legged stool, where all three elements are equally important in providing a stable, balanced platform, the triple bottom line encourages considerations of all factors. As noted in the ASTM E2432-19 standard, "Every building and building product has environmental, economic, and social impacts. These impacts occur at all life-cycle stages in multiple ways and on local, regional, and global scales."

The triple bottom line is a reflection of the need to take a more holistic and long-term view of the effects of a building and its interactions with the surrounding environment in multiple realms, including the environmental, social, and economic effects. All three parts are equally important, although the economic leg has often been given priority, and the other two allowed to falter because the inequities and damages in those realms can be written off as "someone else's problem."

While a short-term approach may seem to work while ignoring the seeming externalities of a particular project, in the long-term, those overlooked factors do not simply disappear because they are not being given consideration. The results from decisions made about a building will occur, whether or not they are addressed in the design of that structure. A sustainable perspective must be broader than looking at the benefits to only a single individual. Sustainability recognizes that nothing occurs in isolation and free of consequences. Rather, there are interrelationships in every decision and that those need to be dealt with equitably.

The People leg of the triple bottom line refers to human health and welfare. The health and well-being of a building's occupants is an important part of this. Certainly, architects are well accustomed to dealing with life-safety questions when it comes to building design. But many other factors are important for the people affected by a building. The materials used in the construction of a building may have negative health effects for the building's occupants as they are exposed to those chemicals.

The Planet leg is the most far-reaching of the three legs. The environmental effects of materials choices can have globe spanning reach. The effects of atmospheric emissions of chemicals used in the construction process, as well as pollutants from building operation, and the carbon dioxide emissions attributable to the operation of the building all have consequences that affect the entire globe.

The Profit leg initially seems to be the most straightforward, in some respects. Every building project has a budget, and architects and builders are accustomed to considering costs and weighing options in the course of a project. But the evaluation needed for a triple bottom line perspective needs to be broader and more inclusive in its scope. Here, profit needs to be understood in a more holistic sense, rather than just the bottom line return for the investor who paid for the building, but the wider web of financial transactions around the creation of the building. Are the workers being paid fairly for their labor? Are the materials coming from sources that do not economically exploit the producers and the inhabitants of the areas those materials are produced? Is the community where the building is located being exploited by tax breaks or demands for infrastructure and services that are not paid for by the building occupants and owners? These issues are also part of the economic arena in which the creation and operation of the building must provide balance, and not simply serve to line the pockets of a limited few individuals.

Pollution and Externalities

Two of the biggest issues that need to be overcome in order to achieve a more sustainable environment are pollution and externalities. The World Bank identifies pollution as "the largest environmental cause of disease and premature death." Pollution is what occurs when any contaminant, toxin, or unwanted substance is discharged into the natural environment, usually stemming from a human-caused source. Pollution is often the waste by-product of industrial processes.

Because it is cheaper and easier to release those products into the environment than it is to contain them and deal with them as part of the manufacturing process, those contaminants are released into the air, water, and land, and the resulting consequences of those materials being in the environment are left to be dealt with by someone other than the originating source of the contamination. Consequences which are unwillingly imposed on others are externalities.

As an economic concept, an externality is any cost that is borne by others outside of an economic activity. Because the economic impact of releasing pollution into the environment is small and does not account for the costs of the harms caused by that contamination, externalities are often regarded as insignificant, trivial, and minor, at least by those who benefit from them. For those who must bear the consequences of those issues, the matter can be much more serious.

Life Cycle Considerations

Life cycle looks at the materials used in construction from a perspective that extends beyond the building's lifetime in both directions. The life cycle begins with the raw material resources that are ultimately turned into the commodity elements and manufactured products that are used for building construction. And, at the other end, the life cycle of these materials extends to the end of a building's life or, in many cases, to the end of a product's life when that particular material reaches the end of its life and needs to be replaced to maintain the building's function.

Buildings are substantial things that exist for a very long time. Because the raw materials and inputs that are used to create products and building components have a value in the time, energy, and effort that went into their production, it is important to preserve that the investment they represent is conserved for as long as possible, to gain as much value from it as can be obtained.

While some building materials may not be a problem in and of themselves, the processes and feedstock used in the production of those materials can involve environmental harms, sometimes in distant places, where it becomes easier to pass them off as externalities. How the materials are processed and manufactured is an essential part of the beginning of the material cycle, and the effects of this production will bear on the network of decisions surrounding the construction of the building. The sustainability of the building can be enhanced by making informed and responsible decisions about the materials that go into the building.

Likewise, considerations for the end-of-life for the materials going into the building need to be a part of the decision process. Some materials can cause contamination and pollution once they are discarded from a building. Some synthetic materials break down into compounds that can be leached into groundwater, or have other negative environmental effects once they are no longer useful to the building. In some cases, where a material can be salvaged and reused or remanufactured into new material at the end of its useful life, that is far more preferable than having the material hauled to a landfill. The preferential selection of materials with recycled content and that are, in themselves, recyclable at their end of life helps to reduce the amount of waste in landfills.

A traditional view of materials was that they existed in a linear timeline, where resources were collected, processed, and turned into goods that were used, and, at the end of their life, they were discarded. This cradle-to-grave progression was in many ways the conventional understanding.

But a different view is more supportive of a sustainable cycle. In nature, everything that is waste from one process is the feed material for another process, in interlocking cycles that demonstrate the essence of sustainability. A tree falls in the forest and it becomes a habitat for a variety of creatures. Insects and fungi feeding on the wood break it down, feeding on it and eventually turning into nutrients that rejoin the forest floor and eventually serve to nourish another cycle of trees.

This perspective for Cradle-to-Cradle cycles was formulated by William McDonough and Michael Braungart in their book *Cradle to Cradle: Remaking the Way We Make Things.* From a sustainable perspective, ideally, everything can serve as a resource to be used for something else. Materials being used in buildings will come from sources that behave in a similar cyclical fashion. More importantly, they will be able to serve as feedstock to eventually serve other uses, instead of becoming waste materials that present issues with their disposal.

The Carbon Economy

Energy is an essential aspect of all manufacturing and construction. Materials need to be harvested, collected, refined, assembled, and all of these processes require energy. Transportation of materials, whether it is the feed stocks used for manufacturing goods or the finished products being transported from the producer to the end user, also requires energy. In pre-industrial times, transportation could rely on the flow of rivers or the power of wind against sails to move quantities of goods. But, in the present day, energy used in almost every commercial process, whether it is for resource extraction or transportation or refinement or assembly, all rely on industrialized energy. The majority of energy used on the planet today involves the combustion of carbon-based materials used as fuels.

In the process of that combustion, energy is released in forms that are usable and are harnessed for human use. But, at the same time, that combustion also releases gases, including large amounts of carbon dioxide (CO2). The Earth's atmosphere now contains roughly 1.5 times as much CO2 as it did in 1950, which is used as a base line.

The levels of CO2 in the Earth's atmosphere have fluctuated in a range between roughly 160 to 300 parts per million over the past nearly 900,000 years. But, some time around the year 1950, the level of atmospheric CO2 began to climb, and is now well outside of that range.

The effects of this extra atmospheric CO2 are many-fold, although it largely returns to the simple fact that increased CO2 in the atmosphere captures additional solar energy, and that energy is transferred to increased average planetary temperature (global warming) as well as increasing the energy in weather and storm systems. The ability of CO2 to act as a greenhouse gas has been well understood for more than a century. Wavelengths of sunlight that reach the Earth and heat the planet are increasingly reflected back to the planet, rather than being able to radiate away. This increases the temperature of the planet, thereby giving rise to a range of negative effects, most notably in increasing the instability of weather systems. Increasing numbers of storms, a greater severity of those storms, record temperatures at both extremes (high and low), and changes in long-term weather patterns are some of the disturbances that have been attributed to these changes to the atmosphere.

As the negative effects of increasing CO_2 levels have become more widely recognized, measures are needed to slow, and eventually stop, the ongoing rise in atmospheric CO_2. Eventually, negative carbon economy may come into being, where either natural or artificial processes are used to actively reduce the amount of CO_2 in the atmosphere, to return the environment to a state closer to what it was in pre-industrial times.

To achieve a balance where, at least, there is no more carbon being added to the atmosphere than is being withdrawn, requires a net-zero condition. Because trade-offs have to be made between some sources that produce excess CO_2 and others that can absorb or extract more, then the exchange process through which that balance is maintained is the basis of a carbon economy. At its most basic level, once the limits of the total amount of CO_2 that can be emitted are set, and then the process of exchanges between those entities that are excess emitters and others that are capable of absorbing or reducing atmospheric CO_2 serves to maintain the overall target goal while still allowing for some entities to be emission sources. Ideally, over time, replacements or new technologies will help to reduce the need for those sources to continue adding CO_2 to the atmosphere, and a drawdown can begin where the amount of CO_2 emissions are less than what is being absorbed, and the atmospheric baseline starts to return towards its pre-industrial range.

The concept of embodied energy or embodied carbon is a related one where the emissions that were produced in the course of the production, manufacture, transportation, and installation of a material are totaled to determine the complete carbon cost for that material. For a building, it would be the sum of the embodied carbon for every material and piece of equipment used in that building. Where renewable energy can be used in the manufacture and production of materials, the carbon portion of the equation is reduced by a bit, but still, much of the processing and transportation relies on equipment and systems that emit CO_2.

Materials that are energy intensive in their production have a much larger embodied energy cost than other materials that are less energy intensive in their production. Just three materials – concrete, steel, and aluminum – are responsible for 23% of total global emissions (most from the built environment). On the other hand, wood is the least energy consuming of the major groups of construction materials. Using low energy, low embodied carbon materials in building is an important element for increasing the sustainability of buildings.

Energy Efficiency

Energy efficiency is one of the cornerstones of sustainability in construction. As is now well known, buildings are responsible for a substantial portion of the total energy used in the world. A report by the US Energy Information Administration of energy use by sector stated, "the residential and commercial sectors accounted for about 21% and 18% respectively—39% combined—of total U.S. energy consumption in 2021." It is important, therefore, to prioritize the energy efficiency of new buildings, especially since the construction of the building envelope will determine the pattern of energy consumption for that building for decades to come.

The design of the building, and more specifically its exterior envelope, will provide the systems that determine much of the energy use for that building. The energy consumed for the construction of a building is only a small part of the total energy it consumes over its lifespan. Because buildings last for such a long time, making them more energy efficient is extremely important for long-term sustainability. The more efficient a building is, the easier it will be to serve its energy needs in a more sustainable fashion, either by reducing the consumption of non-renewable resources for its energy needs, or ultimately to be able to match its needs with a growing capacity of sustainable, renewable energy production.

Retrofits to buildings are always possible, but they are almost always much more expensive to do later than it would be compared with the cost of doing the work properly in the first place.

Materials and resources

The extent to which the use of a material affects the ability of others to also use that material, either in the present or in the future, is an important element in identifying the sustainable use of materials. Whether or not a resource can be replenished is a key factor. One of the most straightforward ways to evaluate the sustainability of a material is the amount of time it takes for that material to be renewed. Many materials have effectively limited supplies and cannot be readily replaced once they are consumed.

Fossil fuels are an example of a material that is constrained to a finite supply. The process of burning a fossil fuel breaks it down from a complex hydrocarbon into simple constituents, a great amount of which is the carbon atoms binding with atmospheric oxygen to form CO2. Because the formation of petroleum took place over a geological timespan, new petroleum is fundamentally not being produced at a rate that will replenish the supply. Once it has been used, it will not be replaced.

Other materials, however, can be replenished over time. Some can be replaced in short periods of time and may therefore be well suited for widespread use. The core activities of farming are largely the encapsulation of this cycle of harvesting and replenishment.

Somewhat similarly, some materials, including metals such as steel, can be recovered after their usefulness has ended and be recycled and turned into new products. While not exactly the same as replenishment, highly recyclable materials can continue to be used for an indefinite period of time by being processed back to an original state and then remanufactured into a new product. Sometimes, due to impurities that are introduced in the process or to characteristics of the material itself, the recycled product is not of the same quality as the original. Paper, for example, can be recycled. But because the fibers are further broken down from the additional processing, and because some impurities from different paper types and from contaminants like ink are in the feed stock, the recycled product is often not as high quality. Many metals, though, such as aluminum and steel are almost infinitely recyclable. The recycling of aluminum requires far less energy (only about 5%) as compared to what is needed for the production of new aluminum from ore.

Plant-based products can be replenished by growing new materials to replace those that have been harvested and used. However, it is not a simple matter of replacement with some of these materials. Not all wood is necessarily interchangeable. Just because a new tree can be grown if an old tree is cut down, does not mean the two are equivalent. There are other disruptions to forests, wildlife, and whole ecosystems that come about from harvesting lumber. Logging a site and replacing the harvested trees with a monoculture plantation of new seedlings is literally an example of missing the forest for the trees.

Even if a material can be replaced in a reasonable timeframe, it may not necessarily be a good material to be used without consideration of the consequences. Consequential effects of the harvesting or extraction of the material can have widespread negative impacts. If these are not adequately accounted for in the use of that material, then it is less balanced in its use. Strip mining and clear cut logging are examples of practices that have widespread damaging effects beyond the simple displacement of the collected resource material. The side effects of these activities causes disruption and damage to the communities and the ecosystems where they take place.

A forest is a much more complex system, and is not just a collection of some amount of commodity building material. Where the logger only sees the value of a forest in its trees, a forest is a much richer and more variable system than that and provides many other quantifiable and un-quantifiable benefits. Too much reliance on any one way of measuring tends to lose alternative perspectives and other ways of seeing things. A key aspect for developing a mindset to understand sustainability is to be able to give consideration to other points of view.

Payback Period

The payback period is an important consideration with the evaluation of any set of design concept options. It is essentially an evaluation of the longevity of each option and comparing that with the cost of operation.

For something that uses energy, the payback period is typically a comparison of the cost of the least expensive, but less efficient, system versus a more expensive, but more efficient alternative. The ongoing energy costs will be lower with the more efficient system, and, at some time in the future, the combined cost of system plus required energy for the more efficient system will be less than the combined cost of the cheaper system. The time it takes to reach that point is the payback period. From then onward, as long as the more efficient system continues to function, the overall cost is lower, and the initial cost from the installation of that system has paid back its additional cost.

Payback period is also applicable to non-energy using components, as well. For example, if one material has a certain expected lifetime and another has a longer lifetime but costs somewhat more, then the comparison may look at the costs in a similar manner. This can be complicated by the costs for removing old materials and for installing the new ones. The evaluation of the payback period should take into account not only the initial installation costs for each of the alternatives, but also the costs for associated materials, labor, and other disruptions involved with changing materials or equipment for a building, so the evaluation needs to take these extra expenses into account as well in order to get a more accurate total cost with each of the alternatives under consideration.

Not every option necessarily requires this evaluation. Because of the developments in technology, in some cases there are materials and components where an alternative selection may actually be lower cost than the conventional alternative it can replace, in which case the decision should be fairly straightforward. The transition in lighting options over the previous decade or so has gone from LED bulbs needing to be considered for their payback period to LED bulbs being the predominant options in many cases.

Red List Materials

There are many manufactured materials which have negative effects on human health and well-being. There are complex chemicals whose activity and properties may produce useful benefits, but whose side effects or other aspects make them undesirable or even harmful to humans. The Red List is an index of materials and products that have been identified as those which should not be included or used within buildings because of the negative effects from their use. The list includes materials that are directly harmful to humans when present in buildings that should be avoided as much as possible. These include materials that are toxic, carcinogenic, or otherwise dangerous to human health.

The Pharos Project was created in 2006 by the Healthy Building Network as a resource to evaluate materials, particularly, but not exclusively, building materials, for the health hazards and environmental impacts of those materials. That work, in conjunction with the International Living Future Institute, has led to the identification of the Living Building Challenge Red List. This is a list of materials, chemicals, and elements that are "known to pose serious risks to human health and the greater ecosystem that are prevalent in the building products industry."

The list also includes materials that have harmful effects from their manufacture. While these may not be directly harmful to the specific inhabitants of the building where they may be used, they are nonetheless responsible for wider environmental harms in the areas where their raw materials are originally harvested, collected, or mined. Resource collection activities can frequently be responsible for widespread harms to wildlife, water quality, air quality, living conditions, and other characteristics in the region.

Part I Review Questions

1. Increased levels of carbon dioxide in the atmosphere cause what negative effects?
    a. Greater quantity of combustion byproducts in the atmosphere
    b. Higher average global temperature and increased storm intensity
    c. Unhealthy air inside buildings
    d. Decline of tropical rainforest areas

2. How should a sustainable design treat issues identified as externalities?
    a. Their effects should be given due consideration and mitigated as possible
    b. They are typically offset by selecting renewable materials
    c. They can be considered as part of the plans for adaptive reuse of a building
    d. They are outside matters that do not affect the building

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II. Synergies and Design

One of the most important concepts in effectively designing with sustainable goals is that of synergy. In short, synergy refers to positive effects above and beyond the sum of the contributing elements. Each constituent decision is individually beneficial on its own. But, in addition, that decision also contributes to additional benefits in other areas. In this way, synergy is a kind of leverage. Because sustainability seeks to reduce consumption and conserve resources, synergistic decisions usually have effects that are helpful in achieving those goals.

Synergies may arise, unplanned, from the design process, as the interrelationships between the different elements of the building are explored and begin to come together. The effects of one system on another may start to be understood within the interactions of the building components, and opportunities can arise to gain multiple benefits as the result of a single component or design decision. Synergies may arise from taking advantage of aspects of the natural environment. Capturing breezes to ventilate and cool spaces without mechanical systems, for example, can use the natural environment and the configuration of the building to utilize effects that are already available at the site and put them to use for purposes of benefit to the building and its occupants.

Systems synergies arise where changes in one system lead to changes in other systems. An excellent example, from some years ago, when lighting fixtures were less energy efficient and generated much more waste heat, was a case where, by changing to more efficient LED lights, the thermal load was so greatly reduced that the HVAC equipment could be downsized, since there was so much less thermal load within the building. Changes to one system not only provide improvements in that system, but the effects carry over into other areas, and the benefits multiply.

Complicated systems are well suited to synergistic effects because of the number of interrelated systems they incorporate. Those connections between different elements are opportunities for beneficial synergistic effects. Because buildings are themselves complex systems comprised of numerous interconnected elements, there are a great many opportunities to look for synergistic benefits throughout the course of the design process.

It is for this reason that systems intended to support more sustainable building design, such as the US Green Building Council's LEED, the Living Building Challenge, and others, encourage an integrated design team that works together to share information and expertise, and continually refine the design over the course of the project. Because of the many ways that different systems may interact with one another, the collaboration is an ongoing process during the development of the project. Design decisions and changes in the project need to be communicated back and forth so that the effects of design decisions can be evaluated and incorporated as it affects different elements of the building. That refinement of the design benefits from the feedback shared with the team as the project design evolves.

Not every synergistic effect arises by chance. Experience with previous projects teaches how the different components in a building interrelate, and where opportunities may exist to Designs for other projects can provide case studies for features that worked together in a beneficial way in that project, and those same features can be used in other projects where similar circumstances exist.

Different material or system selections can have effects in multiple areas. And the effects of one selection versus another will also effect other parts of the space and sometimes even the entire building.

As an example, choosing whether to use wood panels or gypsum board in a space has numerous effects, and the ability to identify and capitalize on potential synergies depends on the project goals and requirements. Even without an energy component, there are still many factors that may favor one or the other of these options. In some cases, one selection or the other may also contribute to the building in other ways. Questions about brightness and light reflection, finish materials, labor required, material sourcing, and many more can be part of the consideration. Selections of light fixtures, acoustic treatments, and other elements may be affected by this decision.

Another example could be using a recycled or reconditioned item rather than a comparable newly manufactured version of the same thing. This can have synergistic benefits extending in multiple ways beyond the interaction with building systems to all three legs of the triple bottom line. Financially, this can be less expensive than the newly manufactured version. From a resource use perspective, recycling keeps materials out of landfills and keeps them in productive use. The energy and resource consumption required for recycling and reconditioning is less than what is required for the extraction and processing of raw materials that is needed for new manufacture. This also contributes to an environmental benefit in reducing the disruption to the environment from mining or other extraction activities, if new commodity materials do not need to be produced in the first place. Along with supporting a better environment, it can also provide a social benefit because the skills required for reconditioning can be higher than those involved in basic material, thereby providing better jobs and better pay for the workers.

Beginning by addressing the functions which the building needs to provide, rather than starting with particular components or systems to provide those functions can lead to synergies where reductions and even removal of systems and elements do not degrade the building's function. The term "negawatts" was coined by Amory Lovins, the former chairman and chief scientist at the Rocky Mountain Institute. A negawatt is a watt of energy that is not used or needed. Finding opportunities where energy use can be reduced or eliminated helps to make the building more efficient in its operation. Fundamentally, the occupants of the building want certain functions and amenities. They are not interested in consuming a particular amount of energy; they just want things to do the things that they expect and to have the building operate in the way that they are expecting it to operate.

Negawatts are, in some ways, more rhetorical than measurable, in the way that any absence is fundamentally not countable. (After all, the number of all of the components that are _not_ used in any building is infinite.) But the principle of the the negawatt is the avoidance of energy usage that would otherwise need to be supplied for a particular need.

If there are two ways of providing a service for the building's occupants, and one uses only half the energy as compared to the other, then choosing the lower energy consumption option yields that difference in negawatt savings. A space that needed 100 watts of illumination, but which instead met the illumination need with daylighting, effectively has 100 negawatts of energy savings from avoiding the use of artificial lighting. The original requirement is still met, but without needing the energy consumption.

An even stronger example is one where not only is the energy consumption avoided, but the material and components that would use that energy are also eliminated. The synergistic benefits are not only the energy savings, but also material and equipment cost, installation labor, and the related elements that are eliminated through the removal of those components. This way there are not only negawatts of energy savings, but also "negadollars" of cost savings coming from not installing the particular elements.

Beginning by determining what is sufficient for the needs in the building, and eliminating unnecessary components provides a building that is sufficient for the needs the building is intended to support. The emphasis is on achieving the desired outcomes, and accomplishing those ends without the need to consume additional energy or more resources yields the more sustainable solution.

Part II Review Questions

3. Synergies can be described as which of the following?
    a. Complications from interactions between systems.
    b. Only occurring when planned from the earliest stages of design.
    c. Cannot apply to all parts of the Triple Bottom Line.
    d. A kind of design leverage that can increase beneficial effects.

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III. The Project Timeline

Project Timeline and Building Lifetime

Sustainability must deal with the entire lifespan of the building and its components and its residual effects. The timeline for the project therefore needs to be treated with a perspective that takes a wider view of the interrelationships within the building, and the networks of influences that extend from the construction and operation of the building. Beyond paying attention to the assembled form for the completed building, the sustainable perspective requires looking backwards to examine the sources that are providing the materials that will be used in the project, and to weigh the consequences that arise from making those selections. Taking a broader view also allows consideration of alternatives that may offer benefits or may avoid particular harms.

More importantly, the design of a sustainable building needs to take into consideration the future of the building. Any good architecture is an act extending into the future. The nature of design envisions a heretofore unbuilt building. But it is not part of regular practice to extend that thinking to the eventual end of the building's useful life; for a great many, that will be someone else's problem, and not their concern.

The design process requires more integration over the course of the project, with less division of the work into discrete segments that can be compartmentalized. While that approach allows for efficiencies from specialization in some directions, it is fundamentally the opposite of the wider perspective that sustainable design needs to draw upon to look beyond the immediate in order to optimize a solution based on a narrow and constrained set of parameters. It is important that the perspective on the project allows for a more complete examination of the web of interactions that extend from the decisions being made to be able to make choices that best support a sustainable approach.

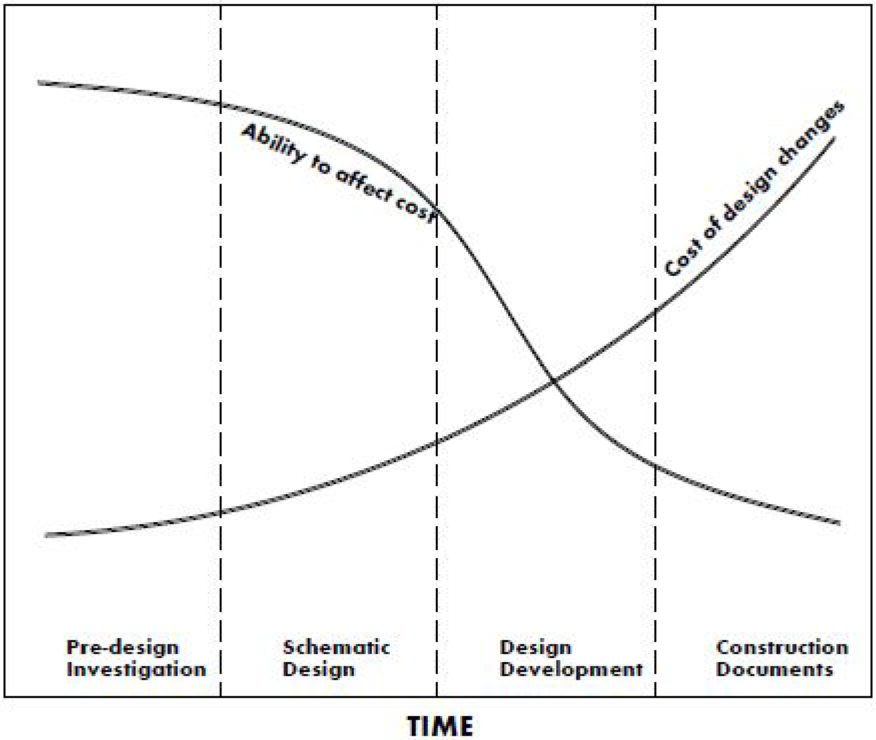
The design needs to take into consideration what the building will be like at the end of its useful life, and what will happen with it at that point. Might it be transformed into some other use at some point in the future? Or is it going to be scrapped and demolished when its functions are no longer needed? And, if there is demolition involved, how damaging is that process to the future environment in which it will be situated? Are there materials that will be difficult or dangerous that future inhabitants will have to deal with?

The concept of cradle-to-cradle design is an important part of the sustainable design mindset. With this broader perspective taken into consideration, one can recognize that all of the materials used for the building need to come from somewhere, and that they all will also eventually reach an end of their useful life and need to be appropriately dealt with. Even if a purely cradle-to cradle material is not available, finding materials that minimize the harms in their production and that can be disassembled or disposed of in the least damaging manner (and that ideally can be turned around to serve as feedstock for another purpose or product).

Conceptual Design

Early decisions will have long term ramifications in the design process. Subsequent decisions on a project are made in relation to the decisions that have already been made. So effectively planning and incorporating sustainability into a project calls for setting out the intent for it to incorporate sustainable principles early in the process. This makes it a part of the project's foundation, as much as the building program itself.

Sustainable design requires taking a wider perspective on the project, extending the designer's awareness beyond the strict limits of the project brief and giving consideration to wider issues. While these may not be at the top of mind for the owners or the occupants or the community around a proposed project, the connections are real between the project and its context. Sustainability calls for keeping those other interests in mind and bringing a balance of outside interests to the project, while still meeting the needs and goals of the project.



Decisions that are made earlier in the design process tend to have lower costs, because the related elements that connect with or rely on those systems and components. Changes, however, become more expensive the further into the design process that the project is when they are made. By attempting to make more of the consequential decisions earlier in the process, the project will be better coordinated, and goals for the project will be more likely to be achieved.

This is not to say that a project already underway cannot incorporate sustainable design concepts. The importance of sustainability is valid at any stage of a project. But, as with any other aspect of design, the earlier it is adopted into the project, the easier it is for that to be reflected in subsequent decisions about the project.

Design and Detail

Recognizing the interrelationships between different systems and components of the building is an important step in developing synergistic strategies to apply for the project. In the same way that the broader concept of sustainability involves taking a wider view of the relationships and context of the building, the same approach, at a smaller scale, can be applicable during the course of the design and detailing of the project.

Synergies are not only present as whole building effects, but also at the smaller detail levels within the building. Synergies can also be found in the individual components and elements of the building. Elements that can perform multiple roles in the building structure or envelope are the small but equally important steps that provide improvements and efficiency in the construction. For example, a structural roof deck that is also a finished ceiling system can use one material in place of several, because a separate ceiling finish and separate ceiling framing are eliminated.

These synergies extend beyond the functioning of the completed building, as well. The embedded carbon cost for the building is lowered by having fewer additional materials incorporated into the building. A leaner list of materials to be installed also means less material needs to be transported to the building site, reducing the carbon footprint associated with the transportation of those materials. With fewer materials to be installed, the construction schedule itself may be shortened, which can provide additional cost savings.

Using materials as finishes may require some additional care and oversight during construction. Workers who are more accustomed to their work being the substrate for other finishes, rather than being the final layer of the building, may need to be coordinated with more closely in order to obtain the intended finish result. Adjacent parts of the building that are connected to those materials may need to be given additional attention as well. Materials may also need to be treated with more care once installed, to protect them while the remainder of the construction work is still underway. For instance, in the example of the structural deck as finish ceiling, the supporting structural framing will also be exposed, and may therefore need added consideration about how it will be exposed, as well. Other systems that serve the building and which would otherwise be concealed in the plenum space above the ceiling will now also be exposed and will also require further consideration. The trade-offs are numerous, and the balance will vary in every case. But giving these ideas consideration is the beginning to finding the best balance of minimizing impacts and providing the most sustainable solution.

Building Lifetime

While it is common to think of a building monolithically, as single thing, it is much more like a living thing or an ecosystem, with different constituent parts playing their part in the whole network of components and systems working together to make what is recognized as a building. While the building itself may have a certain lifespan that might be measured from when it was first built to when it is finally dismantled and removed, the parts and assemblies that make up the building have different lifespans of their own. Since these components provide the functions necessary to keep the building operating, keeping them in good working order and ensuring that they continue to meet the needs of the building occupants is vital for the ongoing functioning of the building.

The different systems that make up a building have different lifespans. In his book "How Buildings Learn," Stewart Brand identified six levels of building systems that interact over the lifespan of a building. Each of the different layers of systems have different ranges of working lifespans. The relative durability of these layers affects how frequently they may need to be addressed over the life of the building.

The six levels of building systems are: Site, Structure, Skin, Services, Space Plan, and Stuff. Site is the land and the surrounding environment. Structure is the principal framework for the building. Skin is the envelope, the exterior walls and the roof. Services are the systems serving the building including the heating, ventilation, plumbing, and electrical systems. Space plan is the configuration of internal spaces and subdivision of interior space. And Stuff is the furnishings, as well as the occupants and the things that they bring with them.

These levels of the building can also be used as an indicator of the relative importance of the decisions made at each of the different levels. The longest lasting decisions have the greatest impact on the building throughout its lifespan. Shorter lasting elements are more likely to be changed over time, and can, therefore, to some extent, be less important to the building in the long term. But none of these elements exist in isolation, because the building is an interacting network of systems.

Lifespans of these elements: Site is timeless, although more recently, considerations of the changing nature of site may need to be given consideration (rising seas and coastal buildings; melting glaciers and ice; transformation of growing zones due to climate changing; etc)

Structure is 50 to 300 years
Skin is about 20 years
Services is 7 to 15 years
Space Plan is every 3 years
Stuff is the constantly changing, unattached contents of the building

It is important, for the operation of the building, for these layers to be integrated together to make a smoothly functioning system. But at the same time, it is also necessary that the different layers be kept separated to allow for changes that are needed over the building's lifetime. Access to these different levels is needed to allow for maintenance, replacement, and even reconfiguration and change as the functions within the building adapt to new circumstances and new needs of the occupants. The life of the building depends on the ongoing functioning of these layers to meet the needs of the occupants.

While the intermediate layers may seem less significant because they represent only a smaller amount of materials, their shorter lifespan and more frequent replacement cycle can add up over the life of the building. So the durability and life-cycle effects of these components needs to be given adequate consideration and not just written off as a less important part of the building. Although these materials may not be as long lasting in the building, it can, nevertheless, be beneficial in the whole arc of the lifespan of those components to choose products that are more durable because their overall life cycle impact will be lower.

Flexibility in Design

Sustainability can also be supported by design decisions that allow for the building to be improved in the future. Retrofitting older systems can rejuvenate the building and extend its useful life. When new technology becomes available, the building can be upgraded with the new systems, keeping it contemporary in its function. Currently existing buildings may be able to be repurposed to new uses, and thereby save the existing structure from demolition, and extend the usefulness of the materials that were used for its original construction.

Likewise, keeping in mind during the design and construction of a new building that it, too, will have a finite life. Allowing for the possibilities of other uses for the building in the future can help preserve the building and retain its usefulness further into the future. An important principle for a sustainable building is that it be designed to have what Peter Buchanan terms "long life, loose fit." Too tightly programming the building will make it more likely to become obsolete. A building with a loose fit can be more easily changed to meet new needs. As Buchanan writes, "It is in large part because historic buildings were conceived in such terms that they are so treasured today. Most historic buildings are proving more adaptable to reuse than buildings from the recent past. This is because the older buildings were not built to minimal space standards and ceiling heights, and they avoided the debilitating extremes of either being tightly tailored to function and the mechanical equipment that serviced them, or of being quite without character so as to be totally flexible. In today's parlance, they are long life, loose fit (and the latter is not the same as no fit). They were also built with materials that lasted and even improved visually and in tactility with age."

At present, roughly 4/5ths of the buildings in existence will still be in use in 2050 - the deadline that many organizations are targeting for net-zero carbon emissions. And the vast majority of buildings built today will remain in existence well beyond 2050. So a long term perspective, looking beyond just the immediate needs, is important in addressing sustainability in meaningful ways.

The decisions made about buildings today will carry forward to future generations who will continue to use and live with the buildings currently being built. Since it is easier and more cost effective to address design decisions at the earliest phases of a project, these issues are important to include in the design thinking from the outset of the project. Not only are buildings responsible for a vast percentage of carbon emissions, but buildings are also the embodiment of decisions that will have the longest-lasting ramifications into the future.

If the designer has taken into account the possibilities that future technologies may offer, then adding or replacing systems will be easier to accomplish. Of course, predicting the future is difficult. Knowing what will be required to incorporate new technologies is never a certain thing, but there are some general perspectives that can be helpful in this regard.

One of the best examples of this principle in widespread use today is Adaptable Design in bathrooms and other spaces. With an adaptable bathroom, for example, although the hardware and elements for a fully accessible facility are not installed, the support structure for those components is included, and the configuration of the room is also done with accessibility in mind. This makes it possible for those elements to be added at a later time, without having to tear out and rebuild the entire room. Comparatively simple measures, such as adding the blocking needed for grab bars to the wall framing, or adding a few inches of space so that accessible space will be available, enable the space to be made fully accessible without having to do extensive renovation. This saves cost and waste at the point in the future when making that bathroom accessible becomes necessary.

Designing for solar panels is another example. With a warehouse or other large, flat roofed building, the expanse of available space may make the installation of solar panels an appealing possibility. But the costs for such systems are still high, and may be too much to include in the building at the outset. However, the roof framing and systems can be designed to allow for solar panels to be added at a later time, and the electrical system can be configured to allow space and connectivity for the wiring and inverters.

The more flexible the systems used in a building are, the easier it is to repair and upgrade those systems in the future. Designers need to weigh these trade-offs when special systems are being considered. But, by incorporating flexibility and adaptability into the design, the building will be better able to be transformed as necessary to serve new needs and accommodate new uses for a long period of time. This does not require the designer to be a clairvoyant who can anticipate what the future needs will be. Rather, it only requires good decisions now that leave room for those developments to occur in the future.

<u>Part III Review Questions</u>

4. Which statement best defines a sustainable design approach?
   a. To achieve sustainability, there can be no trade-offs allowed
   b. Sustainability is a matter of finding the right systems and components needed to provide for all of the building occupants' needs
   c. Sustainability is seeking the best balance between all the competing needs for a building

d. Sustainability is a fixed, absolute goal that every building needs to achieve

5. Which of the following criteria should apply when selecting sustainable materials?
   a. Choosing durable materials and equipment to conserve material use and to extend the lifespan of materials used.
   b. Choosing the least expensive materials to reduce costs and protect the Owner's profit
   c. Choosing materials that are renewable or that do not deplete scarce natural resources.
   d. Both A and C

6. Which is **not** a benefit of emphasizing early decisions and information gathering for a sustainable project?
   a. Decisions made early on tend to be less expensive than changes later on
   b. Early information gathering helps inform more of the design process
   c. Payback period can be extended with an early start
   d. Complicated coordination can be carried out over a longer period of time

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IV. Site Selection Issues and Sustainability

Many elements of the sustainability of the building are connected to the building's site selection. Beginning with the context in which the building will be located (since no system of any kind, let along something as complex as a building, exists in isolation), site considerations are part of the sustainable evaluation. Other factors include the geographic and geological characteristics of the site, and incorporating the impacts and support systems available at the site for the building (for instance, the availability of utility services at the building and the available transportation networks) can play a role in how sustainably a building can operate at a given site.

For any building, the surrounding context is not a blank canvas. There are both natural features and built environment elements that will affect the building. The natural features of an undeveloped site should be identified and understood, rather than simply taking it as an empty space that can be used in whatever way the designer chooses. Existing elements may be useful in many different ways, and should be understood and incorporated, where possible, rather than simply being erased with the footprint of new construction.

Previously developed sites, and those in more urban settings also have an existing context, which includes both natural and social features. The existing patterns of use around a site will both be a source of influences on the new building, as well as being disrupted by that same new structure.

Transportation and Access

Transportation is an important factor, particularly for larger buildings where more public access is involved. For buildings with significant numbers of employees, options in the number of ways to access to the building can play a role in the availability of employees who can get to the building. Depending on the location, transit options can often allow for walking and bicycling, in addition to bus or train access. More options make it possible for more people to get to the building, or for a residential project, for the residents to get to other places they need to go more easily.

For employers, access to transportation can be a feature that allows employees a wider variety of ways to get to their work place. Use of alternative and public transportation reduces the amount of energy in the total building energy footprint. In the wider perspective, every mile traveled to get to a building is part of its overall impact. Where those miles can be traveled in alternative ways, the emissions and the costs are reduced. Although typically treated as an externality, or a factor outside of direct design control, it is the attention to wider ramifications of design decisions that is an important part of making the building more sustainable.

Urban density can be beneficial in that it increases the population in the vicinity of the building. For a commercial or a public building, urban density puts the building closer to more of its clients, users, customers, and employees. Shorter commutes, a transportation system with a wider available variety of more efficient options, and a greater number of people able to access the building by using non-motorized transit all help to decrease the impact of transportation for the building.

These options allow people without personal vehicles greater access to the building. This increases the social equity by making the building more readily accessible for a wider range of people. It also does not rely on the external cost of automobile ownership for some people to be able to access the building, if other options are available. Lower income individuals are more readily able to be both employees and users of the building, thereby increasing opportunities for employment to a wider pool of candidates, as well as making the services the building provides more widely available to a larger part of the community.

By making these choices, and increasing accessibility to the building, the social part of the equity tripod is enhanced. The reduced infrastructure costs that may be possible with a less automobile-centered design can also be beneficial to lowering site development costs for the project. And reducing the reliance on single-passenger vehicles helps in reducing the energy use in conjunction with the operation of the building. Even if this is not directly reflected in the utility bills for the building, the reduction of the associated energy use is still beneficial to the community and the wider environment.

If the building does not require as much parking as a comparable building at an alternative location that was less well served by transit, then there are several issues that come into play. The building without other transit options may require a larger parking lot to accommodate a greater number of cars that must be used by people coming to the building. This is both a larger cost in both initial construction and then later maintenance costs. It also results in more paved area, rather than allowing additional green space to be retained.

Site Features

Site orientation can also play an important role in the performance of the building. The positioning of the sun at the site and the prevailing wind and weather conditions are site features that the design of the new building must take into account. Different orientations of the building may serve to enhance or undermine these effects if they are properly incorporated into the design. Or, if they are not given adequate consideration, then there is a possibility that the design can have some negative characteristics due to the site effects that were not properly addressed.

Energy considerations also are affected by the location and the configuration of the building on its site. Even within a given locality, there may be factors that make one site preferable over another. Access to sunlight due to less shading may be desirable or undesirable, depending on the particular project and its needs. Solar energy is, in some ways, very highly predictable. The path of the sun is well known, and its position can be calculated for any location on the Earth at any time. The designer should take advantage of this to address solar characteristics early in the preliminary design phase, in order to determine what the effects of the sun are likely to be throughout the course of a year for a selected site.

The location and orientation of windows in particular can have a considerable effect on the energy needs of the building. The faces of the building that receive direct sunlight can be passively shaded or adjusted in their orientation if there is too much solar gain. Or the design can be developed to maximize the solar gain for projects where that is a more important factor. Regardless, the effects of the sun on the building can be understood and addressed before getting to the point of adding mechanical systems to the building.

Other site and landscape features and the context of nearby buildings can also affect the natural influences on the building. Trees can provide some shelter from winds, at least for buildings not more than a few stories tall. They also can act as effective, natural, seasonally tuned sun-shading devices. Deciduous trees can provide shading to reduce summertime solar gain, when it is unwanted, but allow for it in the winter, when their leaves are gone. Geography, slope, and contour can also play a role in sheltering parts of a building from winds, or in exposing the building to those same forces, depending on how the relationship between the building and the site is treated. These decisions can also have an effect on the performance of the building with regards to energy consumption and possibly even some aspects of the durability of the building.

Solar Orientation

The importance of solar orientation with relationship to the building is something that is recognized in energy modeling systems and can be an important factor when evaluating the building performance. The design is tested for the effectiveness of the design with respect to solar inputs by testing it with different orientations. In order to generate a baseline for the building, the same design is calculated by being run through the model with four different orientations. For the first one, the building is examined with its planned orientation on the site. Then the building is examined again, but with its orientation 90 degrees off from the planned orientation. The same is done again with the building rotated 180 degrees (so that planned south-facing features are oriented to the north, and vice versa), and then at 270 degrees. The results from this can give the designers an indication of how well the building is responding to site conditions.

If the results of the design condition are significantly better than the averaged base case, then that shows how the building's envelope and configuration are addressing the site conditions with specific measures that improve the building's performance. If there are not significant differences based on the different orientations, then the building is not demonstrating much in terms of addressing the site conditions with the design. In certain cases, that may not matter as much. This does not need to be an automatic indication of failure or of inadequate design. Some buildings may be incorporating features that are less reliant on the specific orientation. A highly insulated building with few openings would likely perform very well in an energy model, regardless of its orientation. But it can be an early validation that the massing and configuration of the building is going to perform well, if the model testing shows that the building shows the best performance in this type of early modeling.

Building in Context

In a denser, urban context, the orientation and presence of adjacent buildings may be under far less control of the designer. But the parts of the building that are more directly exposed to sunlight still should be designed with an awareness of the influences of the sun on the building's energy throughout the course of the year.

Neighborhood context also affects the sustainability of any building. No building exists without connections and interrelationships with its environment. The support services and resources required by that building and its inhabitants come from the surrounding area; the neighborhood and the region where the building is located. This is the context of the building's site, and that context can support the sustainability of the building when taken into account in the design and development of the project.

Business and commercial buildings need to be reachable by their customers and their employees. The importance of "location, location, location" is a mantra that is well understood by real estate developers and property managers. The concept is applicable when looking at a building site from a sustainability perspective, though the kind of location may be a bit different as far as the characteristics that matter.

A contextually appropriate building that works within the neighborhood and region in which it is located is more likely to be a suitable fit. With that, it is more likely to be regarded as a positive contribution to its location, and thereby more likely to remain as a useful building. An important part of sustainability is the ability to remain useful.

Connection Between Interior and Exterior

The connection between the building interior and the exterior is also an important element in the health and happiness of the inhabitants of a building. Numerous studies and tests have shown that natural daylight is beneficial to a building's occupants, and retailers have found that goods that can be viewed in natural daylight are better sellers than those under artificial illumination. Office workers are happier and more productive when they have a view to the outside.

Windows are one of the most complex elements for a building because of the number of building systems they affect. The energy use of the building will be strongly impacted by the size, number, and placement of windows. Solar gain through windows can have an enormous effect on the building's energy needs. The size, placement, and orientation of glazing requires consideration in the early stages of the building design. Site conditions such as the presence or absence of adjacent buildings, trees, and other features can be significant considerations when determining window placement. Both light and heat, as well as the views through the windows are all part of the context for window placement.

Testing early versions of the building envelope and the arrangement of the windows with an energy model can be instructive in examining the effects of the windows on energy useand can help to identify where adjustments can have significant beneficial effects for the building's energy use. In addition to being supportive of the People inside the building, the strategic selection and placement of windows can be important for the overall energy use of the building.

Daylighting can reduce the need for artificial lighting in the building. By designing for daylighting, the energy needed for overall lighting can be significantly reduced, and, depending on the use and function of the particular building, even the total energy needed for the building may be reduced from the amount needed for a comparative baseline building.

Site, Hardscape, and Landscape

The features of the developed site are also important to consider from a sustainability perspective. Beyond the footprint of the building itself, it is also important to consider the choices and impacts concerning the rest of the property. Other elements that are part of the total site include landscaping and, in the vast majority of cases, vehicle parking.

Landscape maintenance is often one of the largest consumers of water for a building. Landscape irrigation for turf and for plantings that require regular irrigation can represent added material and operational costs for the building, with the expenses for installing and maintaining irrigation systems and the cost of potable water where the domestic water supply is used for irrigation. Limiting or eliminating the use of potable water for landscape purposes preserves that water for human needs and uses.

Use of native plantings that are adapted to the local conditions and therefore do not require extensive additional irrigation are one of the best sustainable measures for landscaping around a building. Plants that have evolved in a particular region are naturally suited to that area and can survive with a much lower need for irrigation, fertilization, and other expenditures of effort and cost.

It is always important to work with a local and regional awareness of the best practices for a specific site landscaping and operation. Appropriate sections for each specific project will depend on factors including the regional climate, the plant hardiness zone where the site is located, and knowledge of local best practices for the selection of trees and plants. Factors for the selections for landscape should include plants that are locally adapted, drought tolerant, pest resistant, and non-invasive.

Vegetation

While buildings are designed for the use and benefit of human beings, they are never completely detached from the rest of the world. There are plants and animals occupying the surrounding spaces around every building. In some environments, they may be very limited, such as a densely urban environment where there are few open areas for plants and animals. But even the densest, most completely built-up cities have landscape areas, parks, and other areas where plants can grow. Likewise, although the number of animal species in a city may be greatly reduced when compared to the previously existing landscape before the site was built upon, there are still insects, birds, and dozens of larger animal species in addition to the humans who are in the vicinity of any building.

Because natural systems are thrown out of balance by the upsets to the environment brought on by building construction, some species are displaced or may be killed off, while others find new opportunities to flourish by living among the humans. Insects, rodents, and other nuisance species can find shelter in the small interstices of buildings, where the natural predators that hunted them cannot reach. Or, those larger predators may have been frightened off long ago, when the construction first began, and they were driven from their habitat, or the spaces where they had lived were destroyed. Although the goal may be to keep as much of the exterior environment outside of the building, the designer needs to remember the fact that the building exists in the natural world, and that the way that the building affects the wider world needs to be given appropriate consideration.

Features such as vegetated roofs and green facades, as well as the natural landscaping around a building can contribute a natural beauty to the building. For the building occupants, the presence of vegetation provides connection to the natural world and softens the separation between the building and its environment. Research studies have shown that spending time in a natural environment can be beneficial for human health. Biophilia is the idea that human beings are attracted to living things, and that the presence of plants and animals is something that we naturally seek out and enjoy. Incorporating plants can provide a more positive environment for the inhabitants of a building, as well as for the people in the surrounding community.

Stormwater

The control and management of stormwater is an issue that is often overlooked by much of the public because in so many places it is hidden underground, although there is a huge amount of infrastructure connected throughout most cities to deal with rain and snow. The issue of dealing with stormwater is a growing concern in many regions, where continued growth of the built landscape has overloaded the capacity for storm water management. This is further exacerbated by increasingly unpredictable weather, where intense storm events with large amounts of rainfall in short periods of time can overwhelm stormwater control systems.

In some cases, the design for stormwater management can be used to recharge water back into the ground on site, rather than forcing it into storm drainage systems. The use of permeable pavers, rain gardens, and bioswales all contribute to groundwater recharge, rather than directing the stormwater into engineered underground piping. Treating stormwater as a resource that feeds the beginning of a cycle, rather than as a waste product to be disposed of not only helps maintain water availability by helping supply underground aquifers but can be a more affordable option than the costs for excavating and installing piping and drainage systems that deal with stormwater as a waste product.

Vegetated roofs also contribute in controlling stormwater from a building site. While a conventional roof, whether membrane, metal or shingle, keeps the water out of the building, in most cases storm water is immediately directed into storm drains and into the stormwater system. But the beginning of a storm is absorbed by the growth media on a vegetated roof, rather than immediately being discharged into stormwater systems. Even in a heavier storm, the vegetation and growth media of the vegetated roof help to slow the flow of water so that it does not contribute to the initial onrush of water into the system.

Because storm events can cause the drainage systems to become overwhelmed, solutions that address the stormwater on site, or that delay it so that it does not join in the onslaught of water overloading the storm systems are also contributing a wider benefit by reducing demand for further system capacity, particularly for systems that are reaching or exceeding their capacity. In cases where a municipality has reached its capacity for handling stormwater, it may not be possible to tie into that system. However, using these kinds of measures can help enable a new building to avoid those problems and to be able to be located in an area with inadequate storm infrastructure without causing problems for that system.

Rain Gardens and Bioswales

Rain gardens and bioswales are another landscape feature that serves the building site with natural stormwater control, as well as providing an area of natural planting that can offer beauty and variety to the landscaping. These are two types of landscaping that are designed to serve as mechanisms for stormwater to naturally infiltrate back into the underground water table, rather than being allowed to run off along the surface and be piped away.

Rain gardens and bioswales are similar in many respects. These are both landscape elements that are placed at low points in the landscape. These may be already existing, natural low points in the site, or the contours of the site may be engineered to direct water in the preferred direction to collect at those low points. A swale is a channel or a low part of the site that is intended to collect and direct water along its path. A bioswale is the same, in principle, but with a low enough slope that water moves slowly along its path, thereby giving it longer time to soak into the ground rather than flowing along the surface. It also is planted with plants that are tolerant of periodic flooding.

A rain garden is similar to a bioswale in most respects, but rather than being the path along which water is intended to flow, it is the end-point for that water flow. Sometimes a bioswale may come to an end point which is a rain garden. In other cases, downspouts from a building are directly fed into a landscape area that is designed as a rain garden. The rain garden is designed and intended to flood during heavy storm events, to offset the need to direct that water into storm drains or other engineered systems. Like the bioswale, its function is to contain stormwater to help it infiltrate into the ground.

The soils for these areas are prepared as needed to ensure that there is good infiltration from the stormwater that collects there. The plants that are used for a rain garden or a bioswale are typically a mixture of several different types of plants that do well in wet-soil conditions. Ideally these are native species to the region, since those will be most suited to the local climate and therefore the most likely to survive and thrive. Because this part of the landscape may flood following heavy storms, the plants that are chosen for these areas are varieties that "don't mind getting their feet wet." They are not swamp plants, and the rain garden or bioswale is not normally wet ground, except in the aftermath of rainfall.

Bioswales and rain gardens are also able to remediate some pollutants from the water. Water percolating down through layers of rock and soil is naturally filtered, as contaminants such as fertilizers, pesticides, and oil, among other pollutants, are naturally removed from the water. Even more beneficially, some varieties of the plants that are used for these features are good at phytoremediation (using plants to neutralize or remove contaminants from the environment), and the whole system of plants and microorganisms contributes to improved water quality.

Dark Skies and Bird-Friendly Buildings

Light pollution is another issue related to the building site where sustainable measures can provide benefits to the community and to the environment while also saving energy and money. Building systems that automatically shut off lights at night not only save energy, but also helps to protect migrating birds. Most birds are migratory, according to the Audubon Society, and 80% of those are birds that migrate at night. Birds can become disoriented by artificial light at night, especially in urban areas where the effects are magnified by the sheer numbers of buildings and outdoor lighting.

Controlling light trespass serves several purposes, as well. In addition to having less light pollution that might disturb bird flight, it is also increasingly required in zoning ordinances, where the level of light beyond the property line needs to be controlled so as not to disturb neighboring occupancies. Light shields for exterior fixtures can control the outdoor lighting to limit the amount of light Contemporary outdoor LED light fixtures are often much more directional than earlier bulb fixtures, making it easier to direct the light to where it is needed rather than projecting it in all directions. This makes outdoor lighting more efficient and saves on operating expense at the same time. Judicious placement of site lighting fixtures can provide adequate lighting as needed on the site, while minimizing the amount of light that is wasted on misdirected lighting that does not benefit anyone. Combining these measures with timed operation, or with motion sensors, helps further limit the amount of unnecessary lighting and saves on electrical costs.

<u>Part IV Review Questions</u>

7. Which of the following is unlikely to be affected by site selection factors?
   a. Utility connection cost
   b. Stormwater management strategies
   c. On-site solar power generation
   d. Landscaping requirements

8. Energy modeling provides which?
   a. Comparative information that allows the designer to better understand trade-offs.
   b. Definitive information about the building's future energy bills.

c. Vital information about plug loads and energy use by the building's occupants
d. Speculative information about the lifetime energy use by the building.

9. Stormwater control is best done
   a. On the building site, to recharge the underground water table
   b. By quickly moving surface water to nearby storm drains
   c. By preventing water from soaking into the ground
   d. With central processing plants to filter contaminants

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V. Building Form and Design

While the goals of sustainable design may have cutting edge sensibilities, many of the most useful design strategies rely on long standing principles. High tech solutions are often eye-catching and attractive, but they are also often expensive, and may contain hidden or unrecognized external costs (which may be financial, environmental, or social, or some combination of all three). Effective sustainability needs to be readily available for widespread use, and most technological solutions are limited by cost and by resource requirements that throttle how extensively they can be applied. Measures that rely on fundamental principles that will remain effective regardless of changes over time are highly sustainable because of their endurance and their ability to continue without requiring variable external inputs.

Although solar energy may be thought of as a modern technology, it is really just the more niche aspect of using photovoltaic panels to generate electricity that is the technological element. Basic understanding of solar angles and the seasonal variations of the sun far predates any technical use of the sun for generating electricity. The most fundamental use of solar energy lies in passive design and the placement of building elements to incorporate and balance the effects of the sun on a building. By the selection of materials and placement of openings (among other strategies), the effective contribution of solar gain to a building where and when it is wanted can be maximized and the unwanted gains can be reduced and managed.

Making use of passive solar energy is cost free in terms of future fuel costs, so the building's occupants will be more readily able to continue to occupy and operate the building if the need for other external energy sources is eliminated or reduced. Using solar energy does not compete for other energy sources, which leave those available for other buildings or other uses (or to remain untouched, which, at present, is the best outcome for geological carbon-based fuels).

Passive solar design is dependent on the characteristics of the project site. Different environmental conditions will require different solar design strategies depending on the needs of the building. The climate of the location is also an important factor. A building in a location that primarily requires heating will want to have features that emphasize heat collection and retention throughout the majority of the year. But, even in an environment like this, there is still usually also a need for some level of control to avoid overheating in the warmest times.

Passive use of the Sun is not only an issue for building heating. The Sun can also be used productively to supplement or, in some cases, even replace artificial lighting with daylighting through windows, clerestories, and skylights. Daylighting is beneficial for the occupants of a building. In addition to the operational and energy benefits associated with daylighting, it is also just better for the people inside. Many studies have been done, and it has been consistently shown that workers are happier and more productive in settings where natural light is available. Even just the ability to see the outdoors is associated with psychological improvement over a completely enclosed setting.

Human vision has evolved with the lighting spectrum of the Sun, so the greatest color accuracy is obtained in sunlit conditions. The technology for artificial lighting continues to improve, and the color-rendering index (CRI) for some artificial sources is getting to be very good. But natural sunlight will always be the best for color accuracy.

Not only is daylighting beneficial for providing bright spaces, but having a visual connection to the exterior environment is also better for people psychologically. Being able to see the outside improves the environment for the occupants, and makes the building a more pleasant place to be in.

Fundamentals

Of course, this is all part of the general understanding of the built environment and the fundamentals of how buildings function. Understanding of the basic forces at play for any building and site is important, whether the design responses are based in sustainable principles or not. The design may rely on commercial, mechanized systems that are intended to fight those environmental factors, relying on equipment and energy inputs to respond to those conditions. Or, the design may work with the natural tendencies of those conditions and harness them rather than directly opposing them. A significant part of sustainable design is in understanding those basic principles and in applying them well.

It has been said that the most important aspect of a sustainable building is that is is well constructed. As much as the design may emphasize sustainable intent, if it is not constructed in ways that ensure its proper functioning, it will not last.

Durability

There is a great investment of time, energy, material, and effort that goes into the construction of any building. By extending the lifetime of the building and the time that that the building remains functional, the value of the initial investment of those resources is extended and the benefits that are provided by the existence and operation of that building are enjoyed by a greater number of people. As long as the building continues to meet the needs of its users and occupants, the financial and societal benefits of its continued existence are clear, and the justification for the resources that were committed to its creation is further validated.

The durability and lifespan of a building's existence is an equally important aspect in evaluating its sustainability. Committing costly and limited resources to a project with only a short intended lifetime is equally as bad, and as unsustainable, as using inferior materials for a project with a long intended lifespan. The benefit from building a building needs to be extended over many years to justify the time, energy, money and resources that were committed to its construction in the first place. To ensure that the building will last, it needs to be well constructed following the basic good design, with durable materials that are capable of withstanding the natural forces of sun, wind, and precipitation.

The nature of the different layers of systems within the building can also be a factor in the longevity and functionality of the building. Where systems with different lifespans are intermixed, detaching the components for a system that has reached the end of its useful life from the other, surrounding elements can be difficult. This can lead to keeping that system beyond its useful life and going on and operating the building with inefficient or substandard components. While, on one hand, this may be a resource conservation and a financial savings, it may end up overall as a net negative effect for the building in the long term.

The satisfaction, comfort, and well-being of the inhabitants of a building in failing condition will also be adversely affected. Occupants who have a choice to go elsewhere will likely prefer to go to a different place if the building systems are not providing the expected services and conditions. This downturn in the desirability of the building eventually reaches a point where the building is effectively at the end of its life.

Adaptive Reuse

Adaptive reuse is the adaptation of an existing structure into a new use. Rather than demolishing a structure in order to build something new in its place, adaptive reuse takes the existing structure as the framework from which to build a new building with a new purpose. Adaptive reuse may be a refurbishment of an existing building which maintains most of the structural elements, or it may be a more extensive gutting of much of the previous building, and reconstruction for a new purpose. Fundamentally, it is "recycling" a building.

There can be enormous benefits to an adaptive reuse strategy for a project. By reusing an existing building, sustainability goals are achieved at both ends of the materials life cycle. The production and use of large amounts of new material is avoided, since the existing building is already there. And, at the end-of-life end, those materials also continue to serve a purpose rather than becoming waste that needs (often) to be sent to landfill. This also can be a reduction in the labor needed for the building, with portions of both demolition and construction avoided through reuse of existing structure. In addition, since those avoided construction materials and construction debris do not need to be shipped to and from the site, there is less material that needs to be transported for the project.

Adaptive reuse does not need to adhere to the program and purpose of the existing building. Old building types whose original function is not needed are excellent candidates for adaptive reuse. Many times, adaptive reuse of a building results a completely new function. Old factories being converted into dwelling lofts, for example, are a comparatively common example.

"File:DeadwoodSD LeeStreetStation.jpg" by Magicpiano is licensed under CC BY-SA 4.0.

Adaptive reuse can range from a minor remodeling of the existing structure where the spaces remain mostly intact, even if they are now repurposed to new uses, to an extensive reconfiguration of the original structure to make something that carries only slight reminders of what it once was. Of course, the more radical the transformation is, the more those changes have an increased impact through production and use of new materials, energy expended in transportation and labor, additional waste generated from demolition, and so forth. But, even in a more extensive project like this, the materials and energy budgets are almost always lower than in a comparable case where all new materials were used.

What is the difference between adaptive reuse of a building and a major renovation of that building instead? Functionally, there is not a lot of difference between the two. It is usually the case with either that the major durable elements of a building are what is being retained, and the interior spaces and shorter-lived systems of the building are much of what is being changed. Adaptive reuse is usually involved with the transformation of use from one function to another, while renovation is more likely to be a continuation of the original building's function, but with updated elements to the building. In the adaptive reuse case, the existing building is more likely to be an armature around which new functions are set up, but some kinds of renovation can be equally transformative to the building.

Compelling design arises from finding ways of creating a new space from existing materials. One factor in an adaptive reuse project that many designers relish is the challenge that lies in this transformation. The existing building offers many constraints since its form is already set. But those are also opportunities to create something new with the existing framework providing a starting point for the creation of something new.

The neighborhood context of an adaptively reused building is also typically less disrupted than if the old building were to be demolished completely and replaced with entirely new construction. By retaining some of the existing building through adaptive reuse, the urban character retains echoes of its past in a way that new construction would rarely accomplish. This can make the new building less disruptive to the inhabitants of the surrounding neighborhood, and thereby provide an indirect benefit to the broader social environment with a building that feels like it still belongs for the neighbors who live and work around it. In this way, the adaptive reuse of existing buildings can have wider social benefits by contributing to the revitalization of a neighborhood.

Fundamentally, all architectural design is an orchestration of new assemblies of pieces to create something new and useful; with adaptive reuse of an existing building, one of the pieces is just much larger.

An adaptive reuse of an existing building has other benefits. By working with the longest lasting elements from the existing building (the structure and the exterior shell), the other, shorter-lived building systems (such as internal systems and interior finishes), which may be ready for replacement anyhow, the building is modernized and adapted to suit the sensibilities of contemporary needs. Building systems including electrical power and HVAC can be updated, often with safer and more efficient systems.

Not every building is a candidate for adaptive reuse, however. But there are still alternatives that can keep a portion of the materials from an old building from becoming waste in a landfill. Architectural salvage is the process of recovering the most usable and desirable components from a building before it is demolished. Most often, And while this preserves some of the financial and historic value from a building, this is usually only a very small fraction of the entire value of the building.

Selective demolition of buildings and recycling of materials may be able to recover some value from high-value, readily recyclable materials such as metals. This kind of recycling does keep some materials out of landfills, and that is a benefit. But it is only a small fraction of building material that can usually be recovered in this way.

Part V Review Questions

10. Adaptive reuse can provide what added benefit?
    a. Preserve existing neighborhood character for the present community.
    b. Reduces energy use in the building.
    c. More natural materials are already present.
    d. Better on-site stormwater management with existing structures.

11. Energy used to transport people and goods to a building...
    a. Should be considered as part of the total energy required for operating the building.
    b. Will reduce the LEED score for a building located in a dense urban setting.
    c. Can be offset by installing rooftop solar panels
    d. Does not matter, since it happens off-site.

12. Which of the following is **not** true about passive solar ?
    a. Once incorporated into a building, passive solar has very little or no operating cost.
    b. Solar angles are regular and predictable, allowing effective incorporation into the design.
    c. Where mechanical systems are required, there is no benefit in using passive solar principles.
    d. Shading is also important in designing for passive solar.

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VI. Building Systems

Mechanical Systems

There are a wide variety of options that can be selected for the systems for controlling the building interior environment. Basic forced air furnaces are simple but may not be the most effective nor the most efficient option for a building. And, of course, the issue of carbon emissions associated with systems that rely on the on-site combustion of fuels is still something that needs to be addressed. But alternatives with higher efficiency can provide comfort and environmental control with lower amounts of energy use.

These systems can range for the very prosaic, simple ways to control the building to very high-tech solutions. Basic building science principles are timeless and effective, regardless of the building location. Even with new technologies, the underlying physics of temperature, air, moisture, and materials is unchanging. New technologies offer new ways of addressing those factors, and new materials can offer new opportunities with the control and performance of the building envelope, but the fundamentals are still important in the overall operation of the building.

With the broad range of options, the design of building systems can become a daunting issue to deal with. For commercial buildings, HVAC systems of many different configurations are available to provide a range of options for localized control, balanced operation, and efficient delivery of heating and cooling. Early investigations can help to identify the kinds of systems that will be most effective for a given application.

Smaller scale options are also increasingly diverse, as well. Various types of heat pumps are available, and even in colder regions, they are becoming more worthy of consideration with the ability to operate in below freezing temperatures. Heat pumps are more efficient than traditional heating equipment because they leverage the same thermodynamic cycle as is used for air conditioners. This means that they are able to generate more than one unit of heat per unit of energy used by the equipment. This is an effective coefficient of performance (CoP) greater than 1. Because the system is changing the heat of an existing fluid, rather than converting the energy into heat, it is able to output a greater number of BTUs than if it was simply converting the electricity to BTUs directly. Because of this efficiency, air-source heat pumps are around twice as efficient as electric resistance for heating, and a ground source heat pump is about three times as efficient.

Ground-source heat pumps (GSHPs; which are frequently mis-identified as 'geothermal' systems) use long loops of tubing buried in the ground to circulate a fluid (generally a water/antifreeze mix) rather than relying on heat exchange with the air. Because the ground temperature is very stable as compared with air temperatures, the system's operation is very efficient. Horizontal GSHPs use an array of trenches buried several feet underground, at a depth below the frost line. Vertical GSHPs are better for tight sites with limited open area where a small number of bores drilled a few hundred feet deep serve the same function. Regardless of type, the function of a GSHP relies on the working fluid absorbing or releasing heat to the surrounding ground as it travels through the loop, and then being.
There are only a few degrees of temperature change in the ground over the course of a year, so the efficiency of a GSHP does not fluctuate as widely as that of an air-source heat pump.

Radiant heating can be a comfortable and energy-efficient alternative to forced air systems where the building has overall heating needs. Radiant heating can feel more comfortable than forced air in cold climates because there is not the draft from air moving through the space.
Moving air is naturally cooling because the convective air movement helps move heat away from

warmer surfaces, like exposed skin. But radiant heating is direct heat traveling from the source. Even if the air is cooler, the direct heat from warmer sources, like the floor, still are warming people in the space.

Physiologically, humans are generally warmest in the head, where there is a great deal of blood flow, and coolest in the feet, which are the furthest part of the body from the heart. A radiantly heated floor is ideally coordinated with this need. The coldest part of the body is closest to the heat source.

Radiant heating is good in places where there may be frequent air changes, because it depends on the temperature of a surface, and not the temperature of the surrounding air. When radiant heating systems are used, the overall air temperature can be kept lower, and maintain comfort for the occupants, because they are being heated by the floor surface.


"nobis, Radiant Floor Heating 6-2" by naturalflow is licensed under CC BY-SA 2.0.

Radiant heating systems also frequently use heated water to circulate the heat throughout the building. Because of the greater density of water as compared to air, much more thermal energy can be contained in a smaller space. This also can allow for smaller floor-to-floor levels in some multi-story buildings, if there is less space needed for large ducts for air circulation.

Energy and Heat Recovery Ventilation

Heat- and energy-recovery ventilation systems are components that are especially beneficial in tightly sealed buildings where there is not a lot of air leakage, and fresh air needs to be ensured with a mechanical system. These systems are often separate from the main heating and cooling system, and are mechanical, fan driven systems that bring in fresh outdoor air and, at the same time, exhaust stale air out of the building. The heat and energy recovery portion comes from the system passing the two air streams past each other with a separation barrier that allows heat (and humidity, in the case of energy-recovery units) to be exchanged. In a building heating condition, the cold outside air coming into the building is heated as it passes through channels that are being warmed by the exhaust air that is leaving the building. In cooling conditions, the flow remains the same, but the direction of heat transfer is opposite. This not only keeps more of the energy within the building by conserving the conditioned air, but also allows the building to be more tightly built, with an emphasis on stopping air leaks and ensuring that the building has an airtight envelope. Together, the combination of energy recovery ventilation and air sealing can provide a building that minimizes energy loss but still maintains good indoor air quality.

Building Controls and Open Systems

Large, complex buildings are often centrally managed with building control systems to operate the ventilation and thermal systems, and increasingly, to automate other functions within the building. Occupancy sensors can identify what parts of a building are actively being used and can then control the settings and systems to provide HVAC, lighting, and more for those spaces, and allow other areas to remain without immediate inputs, and without using energy unnecessarily to provide services to the space when they are not needed.

If a space is unoccupied, the heating and cooling for an unoccupied space can be allowed to float away from the setpoint. Lighting can be dialed back or turned off. Other measures can also turn off other unneeded functions to the space until such time as it is needed again. These kinds of savings may be small individually, but, as with many measures in sustainability, the cumulative effect of many small actions can combine together to provide significant improvements.

Balancing between the operational control of the building systems and individual comfort and control of one's immediate environment is one of the more difficult measures to be addressed in the design of a building. Individual control of the immediate environment is helpful for one's happiness in a space on several levels, and this kind of local control is important for the satisfaction with the space for the building occupants. But, for buildings beyond a certain size, the ability to provide individual controls becomes overwhelming, and some level of adjustments are instead made through automatic systems. Features like task lights for individual workspaces in an office environment can be a measure for small local customization. Although individual control for the broader environment is not available, providing a degree of control within an individual's space in a larger area can still allow a degree of personal control, although the larger environment is more regulated.

The passenger controls in an airplane provide an example for this. Commercial aircraft generally have two individual controls for each passenger to adjust their space, a light and an air vent. These give each passenger some personal control and ability to choose the settings according to their individual preference, although the overall environment is set to a temperature that should generally provide comfort to most of the passengers. And overall light levels in the cabin are likewise controlled throughout the plane, but individuals can choose to have supplemental light.

The ability to have some personal control of one's environment makes a space more accommodating to each individual. For an office environment, this can translate into greater satisfaction among the workers, which is a benefit for the workers' comfort as well as contributing to a more productive work environment for the Owner.

Larger buildings also have more complicated needs, with a greater complexity of the systems involved in the building operation. At the larger scale, building control systems are able to manage the environment and the energy usage for complicated structures that can have varying needs depending on the particular function of each space. In some cases, the systems may need to provide cooling to one part of a building while another area needs to be heated. The controls needed to compile the information about the different needs for each part of a building and support those needs with the systems for operation of the building.

Whether simple and straightforward, or a more complex and elaborate system is needed, the building control systems that are used for a sustainable building should use open standards so that they are compatible with a wider range of systems, and so that they can be more readily maintained into the future, rather than needing to be replaced because the old system is no longer supported.

Open standards allow for greater interoperability between different systems and allow for upgrades over time without being locked in to one specific manufacturer's specific systems. They are designed according to general and widely agreed-upon standards, or protocols, that allow for interoperability and wider participation from a greater number of manufacturers. An open protocol allows for systems to be interoperable without being tied to a specific manufacturer. On the other hand, closed, or proprietary, systems are those where the standards and details are not made available and are often kept as "trade secrets." Not only does this limit the number of suppliers available to provide the system, but the operation of those systems requires more specialized knowledge. This can be seen as a benefit to the manufacturer in the short run because it requires the customer to return to them for assistance, repairs, and additional components. Systems that rely on an open protocol, however, are more interchangeable. This means that operators will be familiar with the way the system works, even if they have not used that particular system before, repairs are more readily carried out by any technician who is generally knowledgeable, and parts can be manufactured by more suppliers and are therefore more readily available and less costly.

The protocol is a standardized way of having systems operate so that many different producers can be involved (thereby helping to competitively lower costs) and to encourage widespread adoption and greater development of the equipment environment. New features and functions can be added to an open standard because the way that the system is designed to respond and operate is available to be used. Widespread adoption increases the available options for operation, expansion, and replacement of components.

Automated controls, along with increasing availability and affordability of monitoring devices make it easier to operate a building with access to far more data about its condition than was available in the past. Sensors can monitor temperature, humidity, occupancy, and more. CO2 monitors can determine when more fresh air is required for a space.

If a space has occupancy sensors for one function, that information should preferably be shared with other systems that can also adjust and optimize and minimize energy inputs to the building. Communication between different systems is an important feature for building control sensors and systems. It is an unnecessary duplication, for example, to have one set of occupancy sensors that is connected to the building HVAC systems, and another that is connected to the lighting controls, when the same essential information is being used by both systems.

For building systems that will be replaced or updated during the building's lifetime, it can be important that those elements also reflect more flexible and sustainable approaches. If those parts of the building are difficult or expensive to repair and replace, then the operation of the building will suffer. The perception of the building's condition will be lower if it is encumbered with older, less efficient, more poorly operating systems.

Using equipment and control systems that relies on widely used, standardized, open systems not only increases the design flexibility in the present, but also helps ensure a greater likelihood of being able to continue to use and upgrade those systems into the future. As new developments arise, it is also more likely that those will be able to be incorporated into the existing building more easily, because the standard is already available.

Simplicity

Building control systems deliver a significant benefit to the appropriate kinds of buildings in some cases. According to the US Department of Energy, "A properly designed, implemented, and maintained HVAC control strategy can reduce commercial building energy consumption by 20-30%. Control optimization can reduce energy use by an additional 10-15%." But this is generally only applicable only for larger buildings, where systems of this magnitude of complexity are needed. Many buildings can get by with much simpler systems.

But, at the same time, anything much beyond a simple thermostat requires some knowledge of how the building operates in order to get the comfort and efficiency that the occupants want. This becomes a trade-off that needs to be given sufficient attention for any building project. If the occupants are unaware of the building's systems and how they are designed to provide the comforts of the building, then they may operate those systems incorrectly, which can lead to problems, breakdowns, inefficient operation, and complaints from the occupants. The mechanization of building control has led to less knowledge about how buildings operate, and a reliance on mechanical systems. A return to more incorporation of natural systems can be beneficial from all sides of the sustainability perspective but requires that education for the occupants is a necessary part of the commissioning and start-up of the building.

Even with more mechanized systems, the basic principles of energy, heat transfer, and physics are still applicable, even if they are often supplemented or, even more likely supplanted by mechanical systems. The fact that hot air rises can be used in a high ceiling space along with stratification of the air, allowing hot air to rise above the occupied zone, while leaving cooler air below. The thermal mass of materials can be used to slow the rate of heating due to solar gain and balance out the temperature swings a building may be subjected to, and thereby reduce the amount of mechanical cooling that is needed during the day. Operable shades and awnings can be used to control glare and solar gain during changeable periods of the year when conditions are variable. Active involvement with the natural systems in a building will develop greater understanding of how the building operates and responds to conditions. The operation of the mechanical systems can also benefit from occupants and users of a building who are more aware of how the building functions.

Energy Modeling

Building energy modeling is a mathematical simulation of the energy performance of a building, based on historical or projected information about the conditions, and which can include known or predicted factors such as solar orientation and solar gain, outdoor temperature and humidity, wind speed and direction, and more for the building site. Energy modeling is almost always done with a computer, with some modeling systems able to incorporate an extensive variety of factors. The model contains information about the elements of the building envelope and the systems within the building that consume energy. The characteristics of the building are either entered into the system directly or are extrapolated from information in design software. Parameters for building operating conditions (desired indoor temperature, occupant load, etc.) and a design operating period (very often a one-year period) are then simulated in the model.

The energy model allows testing the interactions of different systems in a proposed building, rather than requiring full scale construction to test different configurations. This allows better performing options to be chosen and optimized. The model can be re-run to test the changes through the design process and may even help identify problem areas when a component or system does not perform as intended or as expected.

Testing with an energy model allows for comparatively rapid and inexpensive evaluation of different design and systems options on the performance of the building. Options such as different wall assemblies, different types and sizes of windows (and different shading options), different mechanical systems, and more can be tested and compared. By changing the characteristics of the modeled building, several scenarios with different equipment can be simulated, with the comparative information about the building's overall energy use, and, depending on the level of detail the modeling software can provide, performance by zone, by room, or even finer detail. This can then be used to guide the decisions about those parts of the building.

Ideally, energy modeling begins early in the design process. The data that is developed from these simulations then informs the subsequent decisions, for example, needing to improve the energy efficiency, if some parts do not perform adequately. Simulation allows for multiple what-if scenarios to be developed and lets the design teamwork with much more information about how the building will perform as a system.

Energy models are best used when they are understood as tools for evaluation and comparison. Since the simulation model uses the same environmental parameters in each instance, the differences between two models are the differences in the design and the alternate materials and systems used for one versus another. The energy model is not going to predict the actual energy use of the building, since there are too many indeterminate variables that will influence the actual usages for the building. But, under the same conditions, different options can be compared against one another, and that information can be used to make the best selections for the design.

Water Use Issues

Water is a resource that needs to be conserved and carefully used, as much as any other resource. Competing demands for water, as a growing population asks for more and more from systems that have reached the limits of their capacity to provide, leads to restrictions and, in some cases, even the rationing of water. Farming, industry, and residential users all need water, but the supply is limited by availability. Many parts of the United States have problems with water source depletion, although the issues with water supply are present across the globe. Depending on the sources a particular area relies on, their capacity to expand production and supply those needs may be limited.

The causes of water shortfalls are often complex, but in many cases, there are real, practical limits to the amount of water that can be supplied. Whether water is drawn from underground aquifers or from surface sources like rivers and streams, there is a limit to how much is available, and, in some cases, those limits are being reached or surpassed. These systems are further stressed when climate events lead to droughts or insufficient rain and snowfall in the source watersheds. Whether or not these events are brought about due to other changes in the climate, the effects are a reality that needs to be dealt with.

Unlike fossil fuels, underground water systems are replenished over time as water percolates through the earth. But, in some areas, the amount being drawn out of the aquifer is greater than the rate at which it is being replenished, and the system is gradually being drawn down over time. This can mean that a water system may become unable to continue to supply any water at all. For systems that rely on surface waters, those rivers are, in some cases, being drawn down so heavily that they functionally cease to be rivers at certain times of the year. Both cases are problematic for their communities.

Costs also rise as the demand also outpaces the supply, and there can be economic benefits in being more efficient with water use. A region that is struggling to meet demand will need to spend resources to provide additional supplies, which will have to come from more distant and less readily available sources, increasing the associated costs to produce and deliver that supply. From a long-term perspective, a region with a precarious water supply way become less desirable as a place where people want to be, and it also reduces the quality of life for those who are there.

In some cases, water consumption can be reduced using "gray water" systems for some needs. Municipal water supplies are treated, filtered, disinfected, and made suitable for drinking, cooking and bathing. But not all used require water that has been treated to this extent. For some purposes, such as flushing toilets or site irrigation, water that has been less extensively treated can be used; this is referred to as "gray water." These systems for this are still somewhat complex, as the water still requires some amount of filtration and disinfection. But, for buildings in locations where water is a very scarce resource, or for places where the stormwater falling on the site requires management and cannot simply be directed into storm drains, it may be worthwhile to capture and re-use the rainfall in a gray water system.

In addition, the direct benefits of reducing water use, another synergistic effect of water efficiency is in energy efficiency. Most obviously, water efficient fixtures like faucets and shower heads that need less water overall will use less hot water than non-efficient versions. And less hot water use is an important savings in energy use. According to the US Environmental Protection Agency, water heating is the second largest residential energy use, behind only heating and cooling.

Additionally, at a municipal level, the treatment and delivery of water is also an energy consumer. Much of the water infrastructure requires energy to operate. The pumps to supply and move water, wells to extract it from underground reservoirs and water tables, the operation of treatment facilities to filter and chlorinate the water for distribution, and the wastewater plants that process sewer outflows before releasing the water downstream are all facilities and processes that require considerable energy. Therefore, reduction in consumption aids in reducing demands on the system.

Part VI Review Questions

13. Reducing water consumption with efficient fixtures also supports which positive synergy?
    a. Reducing water consumption also reduces energy use for water heating
    b. The building requires less dehumidification equipment, which is very costly
    c. The interior air quality is improved
    d. Gray water systems can be used

14. When evaluating the options between all-electric or some fossil systems for a building, which of the following is true?
    a. The option that provides the highest LEED score should be used
    b. It doesn't matter, because electricity is generated by burning fossil fuels
    c. Reduction of carbon emissions should be the driving consideration
    d. Fossil fueled systems are clearly preferred because they are cheaper

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VII. Materials and Finishes

Fundamentally, buildings that are pleasant for their occupants to be in are better buildings. People are happier to be in such spaces. Buildings with unpleasant and uncomfortable environments will be, at best, only tolerated, and if a choice is available, people will seek to go elsewhere. Some of the indoor environment is actively controlled and supplied by the equipment installed in the building. The indoor environment provides appropriate temperature and lighting with the systems and hardware for the building.

The quality of the indoor air is another important part of the conditions inside the building. While the circulation of fresh air into the building plays a role in the interior environment, the materials that are installed inside the building can also significantly affect those conditions. Furthermore, CO2 levels inside a building without sufficient ventilation can lead to tiredness and headaches, and other symptoms. It is important that the building not expose the occupants to harmful chemicals or to materials that can adversely affect their well-being. The materials used in the building, especially the adhesives and finishes that cure inside the space, should be selected with an awareness of how they behave and what effects they can have on people in a building environment.

Indoor Air Quality

For most of us, the interior environment is where we spend the vast majority of our time. According to the EPA, people in the US spend roughly 90% of their time inside buildings. Therefore, the quality of the interior environment is important for our health and well-being. When undesirable gases and chemicals get into the air inside a building, they are more likely to accumulate and concentrate than in the outdoor environment. Since most of the air that we breathe is indoor air, the chemicals and odors that get into that air have more significant effects because we are exposed to them for such a long period of time.

Building improvement programs have mostly been positive, but sometimes well-meaning measures end up creating unanticipated problems. As part of an effort to improve building energy efficiency, air tightness for buildings was emphasized, and the resulting levels of air stagnation and buildup of contaminants was thought to be the culprit for a rash of complaints by occupants of these buildings. Beginning in the 1970s, medical researchers began to identify a set of symptoms connected to buildings. "The most frequent constellation of building-associated complaints is called sick building syndrome. It consists of mucous membrane irritation of eyes, nose, and throat; headache; unusual tiredness or fatigue; and, less frequently, dry or itchy skin. The hallmark of these symptoms is their tight temporal association with building occupancy and their rapid resolution, within minutes to hours, when affected office workers leave implicated buildings. Sick building syndrome is distinguished from more medically serious building-related illness by its subjective nature, reversibility, and high prevalence within implicated buildings and across the nonindustrial building stock in North America and Europe." Being in the building caused the onset of these symptoms; leaving the building and getting to fresh air again fairly quickly led to the reversal of these symptoms.

The materials that are used in the construction and finishing of a building are contributors to these interior conditions. The initial building construction is one key source of chemical contamination in a building. Interior finishes can be a significant source of much of the chemical contamination in the indoor environment of a building. The paint is fresh, sealants have been recently applied, and other materials in the assembly of the building have been recently completed at the point when the building begins to be occupied. Paints, adhesives, and other materials that rely on solvents as a carrier release those materials, which are often volatile organic compounds (VOCs), into the air as they cure and dry and reach their finished condition. VOCs can include many chemicals that can have negative health effects in the short- and the long-term. Many of them have offensive or unpleasant odors.

After these finishes and materials have been applied and installed in the building, the solvents and carrier materials begin to escape into the atmosphere as the material reaches its final state. The volatility of these materials is what lets them be released, and that property is what makes these materials workable. But the net effect is that these materials get into the air in the building, and linger there, sometimes for months or even years, as they slowly dissipate over time.

The result of this is off gassing of solvents, adhesives, and other finish products is detrimental to the interior environment, and leads to negative health issues in both the short and the long term. Respiratory problems are the most frequently occurring health effects, but other adverse health conditions can arise due to exposure to chemicals.

While construction materials are one source of contamination of the indoor air, there are other ways that the building atmosphere may become unhealthy. Dust and airborne contaminants may enter the building through open doors and windows. Air intakes that bring in fresh air through the mechanical ventilation system are another source that can introduce outdoor contaminants, and, once inside a building, those can build up to higher levels than in the outdoors because there is less air exchange taking place than there is in the outdoor environment. Allergens can be another contaminant from the outdoors that are brought into a building that does not have adequate filtration of the fresh air system.

Carbon dioxide exhaled by the occupants' breathing can build up in spaces that are not adequately ventilated. Large concentrations of people gathering together in confined spaces, such as a group meeting in a conference room without adequate ventilation, can lead to much higher-than-normal levels of CO_2 in the air, which can lead to fatigue, lack of ability to concentrate, and may, in some cases, be linked to more serious health concerns. Indoor air also needs to be exhausted from buildings in order to remove odors caused by the occupants themselves.

Poor indoor air quality in office buildings can lead to increased illnesses among employees, which ends up costing the Owner in absenteeism and lost productivity, not to mention the adverse effects on the employees themselves. Healthy air in a building also requires the exhausting of stale air and replacing it with fresh air. Dust and airborne contaminants need to be filtered to be kept from entering the building, and adequate volumes of fresh air need to be supplied in order to maintain a healthy, comfortable environment.

The level of VOCs and other contaminants in the atmosphere inside a building that come from the construction process are at their highest around the point of substantial completion for most buildings. Measures should be taken during construction to minimize these exposures. Where possible, application of off-gassing finishes should be done off-site, where those materials can be contained and allowed to cure before they are installed in the building.

Under some green building programs, there is a requirement to flush the building air before it is occupied, either by natural ventilation or by running all of the mechanical systems for a period of time in order to reduce the levels of those contaminants in the air inside the building. If the mechanical systems are started up while construction is still ongoing, then it is important to filter the air during the remainder of construction. Otherwise, dust and contaminants can get into the ductwork and the mechanical equipment even before any of the end users first set foot inside the building.

Early decisions about material selections need to be made if issues like elimination of Red List materials, ensuring a minimum of VOCs in the building, or other matters is planned for the building. If these decisions are made at the usual point of materials selection – relatively late in the project process – then the need to examine earlier decisions about the material selections becomes an exhaustive process where many already-made decisions have to be re-examined in light of the question about the materials selections. Often, this makes the process too cumbersome and the requirement is relaxed, sometimes to the point of functional worthlessness.

However, if the decisions about the categories and kinds of materials that will be used in the project are made at an early stage, then these checks become easier, and can be incorporated into the design work as the project proceeds forward. Even if the final decision about the allowable levels of certain chemicals or products in the project has not been made, when the design team is conscious of the goals and limits the project intends to follow, then as those material selections are being finalized, the necessary information about those products can be collected. Then, when the final decisions about these materials are going to be made, the trade-offs between different choices can be weighed.

It is important to note that this first phase only needs to be an information gathering activity. In many cases, the final decision can be withheld until later in the process. That is not to say that no decisions can be made at this point. If the team has determined from the early stages to absolutely avoid certain materials, then the presence of those materials in a product can be a disqualification. But the final evaluation can be done in a later phase of the project, and there may be very valid reasons for waiting to make those decisions.

As materials are identified for potential inclusion in the project, the questions about presence or involvement with those categories of concern can be flagged and noted at the outset. Gathering the information at this early stage allows it to be collected evenly and equally for all selections. While zero emissions is the ultimate goal, there are usually some level of contaminants that will have to be accepted. An emissions budget can be set, and then the selections made to keep the project below that limit.

Sometimes, though, compromises need to be made with the materials that are ultimately used in a project. While it is desirable from both a People and a Planet perspective to avoid any use of Red List materials and to avoid chemicals of concern and other products that may have negative effects in the project, not all may be entirely avoidable. It is, unfortunately, sometimes necessary to “use a little bit of a bad thing in order to do a good thing.” One example of this could be the membrane used underneath a vegetated roof system. Although there are many advantages to vegetated roofs (contributing positive effects in many ways, including reduction of heat-island effects; providing natural beauty and habitat for insects and birds; attenuating stormwater effects and reducing runoff and the needs for larger stormwater control systems; and providing a long-lasting roof that greatly reduces the maintenance requirements for the roofing system), the waterproof membranes used with these systems may be vinyl-based materials that cause environmental harms.

The manufacture of an industrial polymer membrane may present serious problems to the community in which that manufacture is carried out (with imperfect, lax, or non-existent regulation of the pollution, by-products, and local effects of that production). But the use of that material may be necessitated by the benefits that material provides. In cases like this, the designer needs to pay very close attention to the choices before deciding to use any problematic material. The decision to use any material from the Red List, or any other problematic or undesirable goods or products must be made with great care. This should not just be a simple A versus B comparison of the relative advantages and drawbacks of each. The extended effects of the entire product life cycle and its impacts throughout the chain of supply and disposal need to be reviewed, so that the decision is as informed as possible. Even with these difficult selections, there are often options that are less harmful. Because these materials are frequently those where the harms are externalized, additional steps should be taken to ensure that those harms are limited as much as possible.

The team may also make a decision to allow a particular product or material into the project, having decided that this is the best overall selection and recognizing that the negative aspects of that selection are more than offset by the benefits that are provided by the use of that material. In this case, the design team can then look at other building systems, and may find other places where a similar material may be in one of the options for another system for the building. In that case, having already admitted a limited use of a particular material, it may be the less harmful choice to use the same material in other parts of the project, rather than introducing even more materials throughout the project.

However, it is by no means true that just because a material with undesirable content is being used in one part of the project, it is okay to go ahead and use it anywhere else in the project, now that it has been included. There may be cases where this does turn out to be the best decision, but there will certainly be other cases where equal or better alternatives exist for those other systems. But, if there is a case where two different options are under consideration, each of them including some roughly similar level of undesirable materials in their makeup, but one of those has materials already being used in another part of the building, then it may be preferable to choose that one from the standpoint of limiting the number of different undesirable materials being used in the project overall. If measures are being taken to mitigate the presence of those materials, then it will generally be easier to deal with a bit more of that material elsewhere in the project, rather than having multiple different strategies that need to be used for different parts of the building.

Reduction of the number of different materials used in the building can also help with managing these issues. By having a more limited palette, and the accompanying issues they potentially represent, the design team can also help in managing the amount of work needed to ensure the interior environment is going to be as healthy as possible.

There is a further synergistic benefit in this approach. In addition to providing a better interior environment, it also helps in controlling material and construction labor costs by having fewer products that need to be installed.

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VIII. Commissioning, Operation, Maintenance

The construction of a building is only the first step in the long period during which it will serve its purpose, and supply the functions that it provides for its occupants, users, and the wider community context in which it is located. The design of the building sets it on its trajectory, and the sustainability of the building is strongly affected by the decisions made about its construction. The selected orchestration of materials will be in place for decades, or even longer. Well selected, well designed assemblies of materials and systems should continue to serve those functions over the life of the building, and those that do not have the durability and longevity to match that of the building need to be able to be maintained, repaired, and replaced during the life of the building to ensure the proper ongoing operation of the building.

Buildings are highly complicated, interrelated systems that need to perform multiple functions to ensure the well-being and comfort of the occupants inside and around the building. The design of the building is the statement of intent for the building, but that intent needs to be followed by the proper execution of that plan. The commissioning process is used to ensure the proper functioning of the building systems, and to bridge the connection between the design and the construction. Commissioning is about the performance of the building, but since the sustainability of a building is reliant on how well it performs its functions, commissioning to ensure that those functions are being performed as designed is an important part to be incorporated into the overall execution of the building construction.

The Cost of Commissioning

Energy, water, productivity, and operational savings resulting from commissioning offsets the cost of implementing a building commissioning process. Recent studies indicate that on average, operating costs of a commissioned building range from 8–20% below that of a non-commissioned building. The one-time investment in commissioning at the beginning of a project results in reduced operating costs that will last the life of the building. In general, the cost of commissioning is less than the cost of NOT commissioning. Continuous commissioning is an enhancement to O&M that typically makes facility operations and management more efficient.

The cost of commissioning is dependent upon many factors, including a building's size and complexity, and whether the project consists of new construction or building renovation. In general, the cost of commissioning a new building ranges from 0.5–1.5% of the total construction cost. For an existing building, never before commissioned, the cost of retro-commissioning can range from 3–5% of total operating cost.

Costs of Commissioning, New Construction

Commissioning Scope	*Estimated Cost*
Entire building (HVAC, Controls, Electrical, Mechanical)	0.5–1.5% of total construction cost
HVAC and Automated Control System	1.5–2.5% of mechanical system cost
Electrical Systems	1.0–1.5% of electrical system cost
Energy Efficiency Measures	$0.23–0.28 per square foot

Source: Building Commissioning Guide. Version 2.2. 1998. DOE/GSA.

The Los Alamos National Laboratory Sustainable Design Guide defines commissioning as, "a systematic process of ensuring that a building performs in accordance with the design intent, contract documents, and the owner's operational needs. Commissioning is fundamental to the success of the whole-building design process. Due to the sophistication of building designs and the complexity of building systems constructed today, commissioning is necessary, but not automatically included as part of the typical design and contracting process."

https://engstandards.lanl.gov/esm/architectural/Sustainable.pdf
https://www.energy.gov/sites/prod/files/2013/12/f5/sustainable_guide_ch9.pdf

Commissioning ensures that the building is operating in the manner that it was designed and intended to operate. Even if the pieces are in place, if they are not working together in proper coordination, the building may not be working as effectively or as efficiently as it was designed to do. By having a commissioning agent for the building to verify that operating systems are operating, and that their operation is performing the intended functions, the building should behave in the ways that the design team intended.

Commissioning also can include training for the building operation staff or the building occupants. Although there are many automated systems to perform a great number of functions as part of contemporary buildings, it is still necessary to for the occupants and staff to keep the operation of the building on course and ensure that it is conforming to the needs of the building inhabitants. Another part of the commissioning process is to ensure that the maintenance requirements of systems in the building are outlined to those who will be responsible for their operation, so that those systems are kept in proper condition.

Although not yet widely practiced, an emerging concept of continuous commissioning is the next step in the building commissioning system. As distributed and embedded sensors become more widespread, and building equipment incorporates more and more "smart" technology, the ability to monitor the status of building's systems will grow. Continuous commissioning looks at the ongoing operational needs and uses of the building as they develop and change over time and adjusts the systems to meet those needs.

Continuous commissioning can also be beneficial for building operation and maintenance. Building operators will be able to more quickly identify trouble conditions within the building, and can respond to these conditions sooner, perhaps even before a system has reached a point of failure. This data will also be able to be used to compare the performance of the building to anticipated performance. With this greater detail of information, it may be possible to adjust building systems to improve their performance based on the feedback about how systems are actually working. Over time, as well, it may allow reconfiguration of operation to better respond to the functional changes that occur with the use of the of the building as the occupants' needs change.

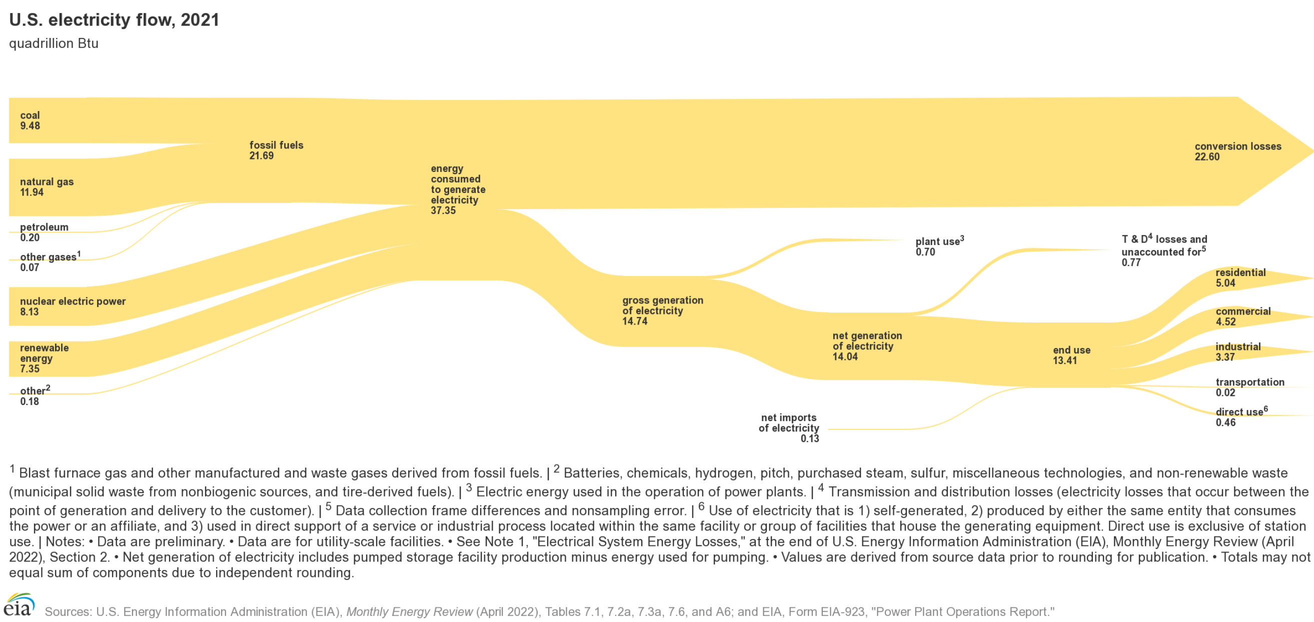
Energy efficiency is a key goal is sustainability. In the present day, more than half of the energy consumed for buildings is derived from non-renewable, fossil sources. Therefore, measures to reduce consumption and extend availability of those resources into the future (as well as the mitigation of the harmful effects from the atmospheric carbon dioxide buildup) are all important. Continued tracking of the energy used by the building can identify if there are issues that need to be addressed. It may even help with identifying mechanical issues before systems actually break down.

Because the energy use of a building is an ongoing consumption of resources (in most cases; there are a few non-energy-consuming buildings, but even off-grid buildings and net-zero buildings consume some energy), keeping track of that usage to note changes or increases in the amount of energy being used is important. Changes may come from a number of sources. It may be a result of the building increasing the number of occupants, especially as building usage and occupant volume ramps up following the original opening of the building. Changes may also be due to external factors, or changes in use patterns that are not directly caused by the design of the building itself. Or they may be an indication of systems that are not performing at the levels they were originally operating at. In all of these cases, maintaining the target efficiency of the building requires feedback of this information. When repair or adjustment is required, the feedback of how the building is operating is important information in identifying issues in order to be able to diagnose and correct those issues.

The initial selection of energy systems for the building can be an important consideration for the building. Although this needs to take place in the early design phase, this is a decision that can have ramifications that carry on through the entire life of the building. This may be a decision that is driven by the availability or unavailability of some utilities.

Choosing an all-electric building immediately sets the building on a path for greater carbon emission reduction, since it will not have a reliance on fossil fuels for heating, cooling, and other energy needs. With no on-site emissions from the building, it will present a comparatively smaller carbon footprint than a similar building that uses fossil fuels for some of its energy needs. Even if the electricity being used by that building is being generated by fossil fuels at the utility level, this is still a positive tradeoff for several reasons.

In the mix of sources producing electricity for almost every grid there is some level of non-carbon-emitting electrical generation. According to the US Department of Energy, energy sources for electricity for the United States in 2021 was about 42% from renewable sources (including wind, hydroelectric, solar, geothermal, and various biomass sources) and nuclear, and about 57% from carbon-emitting sources (primarily coal and natural gas).



https://www.eia.gov/totalenergy/data/flow-graphs/electricity.php

Retrofitting equipment already installed in a building is already a costly undertaking. If that replacement also involves changes to the building's utility requirements, the cost and complexity of that change is much greater. Not only does new wiring and other electrical equipment need to be added for converting from gas-fired equipment to electrical, but also, the old gas distribution infrastructure within the building needs to be removed, or abandoned in place, with the accompanying waste of materials and labor which were committed for the installation of those systems in the first place.

Over time, the amount of renewable, sustainable sources in the electrical generating fleet is going to become greater. The costs for electrical generation from wind, solar, and other renewable sources are increasingly competitive, and the share of new construction with these systems is continuing to grow. Fundamentally, over time, the grid is trending towards phasing out its carbon emitting plants and adding more capacity in zero-carbon sources. So, even if the regional grid is not immediately at the forefront of carbon emissions reduction, the trend is clearly in that direction.

While the design of a building may be intended to provide high performance, the operation of that building by the occupants will ultimately determine how successfully that is carried out. Training and education of the staff responsible for the building operation, along with commissioning to ensure that the systems are operating properly from the outset is critical for the ongoing functionality of the building.

The occupants of the building need to participate in the proper operation of the building, as well, and to cooperate in seeking to continue the sustainable operation of the building. Depending on the complexity of the systems in a building, the occupants may need direction or training about the use of some components. Spaces with a lighting system connected to occupancy sensors and automatic controls will not deliver on the intended performance efficiency and energy savings if the users of the space regularly override the system to turn on the lights. The building's occupants are equally if not more important to the sustainability goals for the building, and their involvement is what drives the day-to-day operation and energy use of the building. Ultimately, even the most sustainably designed building will fail to live up to its potential if it is not operated in the appropriate manner.

Regular maintenance of the building also helps to ensure its sustainable operation. There may be systems or equipment that require periodic adjustment to remain functioning in an optimum manner. Filters for air handling systems keep contaminants out of the interior environment and need to be replaced regularly. They also can degrade the performance of the air handling system over time if they are not replaced when required. Other functional systems likewise need to be regularly checked and kept within proper operating parameters. Repairs need to be carried out quickly, when failures in systems do occur, to minimize the disruption and functional loss in the building.

Longer term maintenance may include regular periodic inspections of the exterior envelope for deterioration, damage, or failure that could affect the structure and the underlying elements of the building structure. Replacements of failed components also needs to be carried out with the same standards as applied with the original design and construction of the building. Selections for replacements and upgrades to building equipment need to be done to ensure that the original function is maintained or improved. But also, it is important to ensure that there are not adverse effects from the replacements (whether intentionally or not) that affect other systems or building components in ways that the original system did not. Circumstances like this can occur when there is less investigation into the new components because the work is seen as merely repair or replacement of a part, rather than something that can adversely affect building performance. Although the staff operating the building may see this as a like-for-like replacement of one component with another, some factors that were part of the original design selection may be overlooked. For example, the original windows for a building would have a whole range of properties that were included as part of the design. But, when those windows are replaced at some point in the future, it may be that the new windows have a better U-factor at the center-of-glass than the old ones had, but the new windows have a different solar heat gain coefficient so that their performance is no longer in harmony with the operation of the building.

While these are, on the one hand, simple and obvious steps that should be performed for every building (and equally so, every building should arguably be a sustainable building), the maintenance of the building and its systems are also as much an important part of the ongoing performance of the building as a sustainable facility.

Part VIII Review Questions

15. Maintenance is important for the ongoing sustainability of a building for all of the following reasons except which?

a. Operational efficiency is retained and reduced carbon emissions are limited when equipment is in proper operating condition.
b. Equipment that is maintained in good condition will continue to operate longer, thereby extending its working life and reducing cost and the need for replacements.
c. If not properly maintained and operated, functions that the building was designed for may not be properly supplied
d. Maintenance costs can be avoided by buying more expensive systems that will last longer.

16. Energy efficiency for a sustainable building is...
    a. The number one goal for any sustainable building.
    b. An important part of reducing carbon footprint and operational cost
    c. Less important if a building uses extensive on-site renewable power generation.
    d. Always a trade-off with building comfort

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IX. Programs and Regulations

Many programs exist to assist the design team in evaluating the myriad of components and materials that go into the construction of a building, and to help with the selection of those that do the most to promote sustainability for the building. As with any tool, however, these must be used appropriately. It is important to recognize that simply using a material from a particular list or checking off the boxes on a scorecard are steps that can help the team to deliver a more sustainable building but are not enough to guarantee that the project must be sustainable because those few steps were followed.

Product Certifications

In addition to the certification programs for buildings, there are also numerous accrediting bodies that address particular subsets of materials or equipment, and also offer labeling and certification for those products to assist in making selections with particular characteristics or qualities that support sustainable goals.

Industry groups and government agencies have likewise arisen to develop standards and criteria for their sectors that recognize best practice measures for the characteristics of their products and the ways in which they are produced. Most of these certifications and labeling programs are intended to be useful for the designer to be able to get information about the sustainability of the materials and products under consideration. But there is a marketing aspect to many of these programs, as well, and some programs may be more about greenwashing than they are about truly making a difference in the sustainability of the offerings in the particular subject category.

If an unfamiliar program is being touted to certify a particular item, it may be necessary to evaluate the program first, and see whether the guidelines for its labeling are sufficiently specific and limiting that they are making a meaningful distinction. One resource for use in considering the strength of a product labeling program is whether or not it is included in the EPA's "Recommendations of Specifications, Standards, and Ecolabels for Federal Purchasing" This list is not exhaustive nor exclusive, but can at least be a starting point to use in vetting whether or not an unfamiliar labeling program has meaningful and widespread adoption. Whether or not it is adequate for a particular project's needs and goals remains an issue to be determined by the design team.
https://www.epa.gov/greenerproducts/recommendations-specifications-standards-and-ecolabels-

federal-purchasing

Energy Star is a program administered by the US Environmental Protection Agency that works in conjunction with industry partners to address five key areas of energy efficiency: Products, Existing Homes, New Homes, Commercial Buildings, and Industrial Plants. Energy Star labels on a wide range of appliances and equipment help to identify energy efficient selections for consumers and businesses. The certifications are tested by independent third-party evaluators to verify performance requirements. Products with an Energy Star label are more energy efficient than the average within their category. Like Energy Star, WaterSense is another EPA program, this time focused on water use. According to the EPA, WaterSense-labeled products use at least 20 percent less water than other, non-WaterSense models.

Cradle to Cradle Certified Product Standard was originally connected with the authors (McDonough and Braungart) of the book but is now a separate program operated by an independent organization, the Cradle to Cradle Products Innovation Institute, which certifies products based on five categories: Material composition, Material reutilization, Energy for Production, Water use, and Social responsibility. Products are certified at different levels based on their achievements within these categories.

As a counterpoint to the Red List of materials to avoid, the International Living Future Institute has established a database of products listed with their Declare label. The Declare label contains information about the absence or presence of any Red List materials in the product above 0.01% by weight, as well as information about the location of origin, life expectancy, and other characteristics that the design team needs. "In addition to the LBC Red List, the Declare label demonstrates alignment with other requirements within the Living Building Challenge and Core Green Building Certification, as well as LEED and WELL certifications. These requirements include ingredient disclosure thresholds, VOC content and emissions, embodied carbon, and responsible sourcing, including FSC Chain of Custody."

These programs can be used as guidelines for selections for a building. Part of the early decision making can be to identify programs and standards that will support the goals for the building. In some cases, there are different levels of achievement within a program, and only materials meeting one of the higher levels of performance may be appropriate for the building. Using the standards as the initial criteria for these choices, the overall project goals can be identified early on, without needing to make final selections at the outset.

Building Rating Programs

There are several voluntary programs that designers can use to support and demonstrate the sustainable features of a building project. Programs such as LEED, the Living Building Challenge, Green Globes, and EnergyStar, among others, provide systems for documenting and scoring the sustainability of a building according to their particular sets of established standard criteria.

Building rating programs generally score a building based on its design characteristics. Some systems also include performance audits or other post-construction assessments of the completed building. However, the main emphasis in most systems focuses on three principal areas. Energy efficiency and performance is usually the largest category of scoring, along with ratings for the materials used, and for the interior environmental qualities of the building. Points are acquired according to the program criteria. Energy performance is usually measured against some comparative baseline. Improvements in efficiency that go beyond the baseline earn points according to the formula for the program.

Most of these programs also have certain features or elements that will score added points for the building, whether or not they are actually used by the building occupants, and whether or not they are appropriate for the building in question. In some cases, the rationale for assigning points to these particular points of focus is to encourage more widespread adoption of those features.

Points from all the different categories are then totaled to give a final score for the building. Some systems have different tiers for the rating, in order to rank performance, while others are a more basic pass/no-pass assessment of the building.

Programs

Certification through a third party can be useful in collecting objective information about a building's performance. This data can be used to examine the present operation of the building and help in identifying areas where the efficiency of the building can be improved.

LEED (Leadership in Energy and Environmental Design) is a program that began in 1993 to bring together a broad range of building professionals representing architects, builders, manufacturers, and suppliers - all groups with a stake in the building industry - to work together for a green building system. The US Green Building Council was formed and began developing the guidelines for what became the first version of LEED.

According to the USGBC, "LEED is the world's most widely used green building rating system in the world. Available for virtually all building types, LEED certification provides a framework for healthy, highly efficient, and cost-saving green buildings, which offer environmental, social and governance benefits. LEED certification is a globally recognized symbol of sustainability achievement and leadership." LEED evaluates buildings in five major categories: Site and infrastructure, Water, Energy, Materials and Resources, and Interior Environment.

Buildings also can be certified through the Energy Star program for commercial buildings or for industrial plants. The Energy Star certification for buildings indicates that the building performs better than 75 percent of similar buildings. Although the program is a national rating, the system accommodates regional conditions and differences to balance the scoring. Unlike some other programs, the Energy Star certification is based on building operation and actual energy use, rather than on the design of the building. The Energy Star rating is also re-calculated each year, so the performance of the building needs to be maintained in order to retain the designation.

Unlike most other programs, the Energy Star rating is only concerned with energy use of the building. Other factors such as the materials used for the construction of the building, water consumption, and the indoor environment are not a part of this rating system.

The Living Building Challenge is a program that began in 2006 to encourage building to a standard that goes beyond doing less harm and seeks to create "regenerative" buildings. "The Living Building Challenge consists of seven performance categories, or "Petals": Place, Water, Energy, Health + Happiness, Materials, Equity, and Beauty. Each Petal is subdivided into Imperatives, for a total of twenty Imperatives in the Challenge. The Imperatives can be applied to almost every conceivable building project, of any scale and any location—be it a new building or an existing structure."

Like the Energy Star program, the Living Building Challenge is based on actual performance. Therefore, the completed building must be in operation for at least a year before it can be audited, rather than using modeling or other measures of anticipated performance.

Voluntary Standards

All of these programs are voluntary programs. The measures that need to be followed to improve the sustainability of a building are optional, rather than being required by requirements in the building code. Sustainability, however, is more than a number or a score. The principles of sustainable design do not rely on any particular program or system in order to be effective. Sustainable design can certainly be achieved without going through any system of certification or accreditation. Voluntary programs can provide resources for the design team to be able to identify and coordinate the measures that they intend to use for a given project. The guidelines set out goals that are performance thresholds for the team to meet. These can be used by a project client to express the broad goals for the project to the team. But reaching a target number does not mean that a building is now "sustainable" instead of "unsustainable."

The various rating programs may not necessarily recognize some of the benefits that certain features may contribute to a project because each program has its own systems and metrics for scoring and quantifying how sustainable a project is. There may be some features that are highly scored, whereas other elements may not be recognized by that particular program. Generally speaking, however, any highly sustainable project is likely to score well in any of these evaluations. But just because a building has scored well in a particular program does not necessarily mean it is automatically a sustainable building.

The results can sometimes be mixed when evaluating buildings designed to meet a program standards. There have been some criticisms of the various green building rating programs, and the results where some buildings have gotten high rating scores despite there being problems with those buildings. A study looking at federal buildings certified under the LEED program found that they were not necessarily using less energy, although other studies have found better results. A commercial study of "high-performing federal buildings" (including many LEED certified buildings) found that "they used 23% less energy and 28% less water, along with other savings." Other examinations have had similar positive indications. It may also be the case that "buildings that are upgraded and LEED-certified may simply be nicer or more accessible and get used more."

This certainly is a positive outcome in the wider perspective of a building getting more use. If the building is being more appreciated by the people who need its functions, and it is serving a greater number of people, then its functionality is an improvement, even if the comparative energy consumption is higher. A building that is liked by its occupants and by those who need to visit it is more likely to extend its useful life, which carries significant sustainability benefits, as well. From the perspective of a community's involvement with a building, this might be a more important measure of its value on the 'People' leg of the sustainability triangle than other factors that are measured by a rating system.

Decisions that choose to not consume materials also do not figure well in the rating systems despite the fact that 'Reduce' is the first word in that other great sustainability catchphrase of, "Reduce, Re-Use, Recycle." Only things that can be counted can be measured in a scoring system, but there is no scoring that rewards making the building smaller and more efficiently using the spaces that are created, even though that can have a much greater overall impact than the selection of more efficient systems.

Choosing not to use a finish product, and instead allowing the natural surfaces of a material to be exposed, does not have much, if any impact in a rating system, despite that being a very sustainable choice, because it cannot be scored in a similar way to other material selections.

When the construction team chooses to use a rating system, it should be recognized as just one tool to be used in the quest for a more sustainable outcome with the building. Information and data of all kinds is vital to understand and evaluate the characteristics and performance of a building. It is also important to measure the appropriate things, and to give them the appropriate weight, but not to overvalue something simply because a number can be attached to it. The energy consumption of a building is an important set of data to have. But the sustainability of the building is much more than a measure of how much energy it consumes.

It is not necessary, however, to use any of these rating systems in order to create a sustainable building. The rating systems do help in providing a framework that can be used to manage the team's goals and keep the project on track. Some of the specific requirements can be helpful in setting some of the initial boundaries for a project. The various rating systems offer a wealth of information and resources for the design and construction of a sustainable building. The manuals and guidelines of these programs have considerable recommendations, and best practices that can assist in meeting the sustainability goals for a given project.

Rating systems do provide a third-party verification for the characteristics that are measured and monitored by those programs. This helps with the confirmation and acceptance of the building having the qualities and characteristics that are claimed for it. But the essential core of what needs to be done for a sustainable building relies on the design team understanding the wider perspective that is needed to create a sustainable building. The checklists can aid towards incorporating sustainable principles in the design, but ultimately, the sustainability of a project comes through the work of the design team.

Part IX Review Questions

17. What is the greatest benefit of using US Green Building Council LEED during the design of a building?
    a. Additional credit for the adaptive reuse of existing buildings.
    b. Prohibits inefficient equipment from being used in the building
    c. Availability of extensive resources for more sustainable practices
    d. Measures the efficiency and carbon footprint of the building

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Review Question Answers

1. Increased levels of carbon dioxide in the atmosphere cause what negative effects?
   a. Greater quantity of combustion byproducts in the atmosphere
   b. Higher average global temperature and increased storm intensity
   c. Unhealthy air inside buildings
   d. Decline of tropical rainforest areas

B is correct. A and D may be linked to the causes of increasing CO2, but are not caused by it.

2. How should a sustainable design treat issues identified as externalities?
   a. Their effects should be given due consideration and mitigated as possible
   b. They are typically offset by selecting renewable materials
   c. They can be considered as part of the plans for adaptive reuse of a building
   d. They are outside matters that do not affect the building

A is correct. B and C - these does not address the issue. D - this statement is counter to sustainable principles.

3. Synergies can be described as which of the following?
   a. Complications from interactions between systems.
   b. Only occurring when planned from the earliest stages of design.
   c. Cannot apply to all parts of the Triple Bottom Line.
   d. A kind of design leverage that can increase beneficial effects.

D is correct. A - although resulting from interactions between systems, synergies are beneficial effects. B - discovering synergies early on can be helpful, but they can be found at any point. C - positive synergies across all three parts of the Triple Bottom Line are desirable

4. Which statement best defines a sustainable design approach?
   a. To achieve sustainability, there can be no trade-offs allowed
   b. Sustainability is a matter of finding the right systems and components needed to provide for all of the building occupants' needs
   c. Sustainability is seeking the best balance between all the competing needs for a building
   d. Sustainability is a fixed, absolute goal that every building needs to achieve

C is correct. A - trade-offs and balance are central to sustainable design. B can be important, but wider needs than those of just the building occupants need to be considered. D - there is no absolute definition of sustainability.

5. Which of the following criteria should apply when selecting sustainable materials?
   a. Choosing durable materials and equipment to conserve material use and to extend the lifespan of materials used.
   b. Choosing the least expensive materials to reduce costs and protect the Owner's profit
   c. Choosing materials that are renewable or that do not deplete scarce natural resources.
   d. Both A and C

D is the correct answer. B - protecting the Owner's profit is not a goal for sustainable design.

6. Which is **not** a benefit of emphasizing early decisions and information gathering for a sustainable project?
   a. Decisions made early on tend to be less expensive than changes later on
   b. Early information gathering helps inform more of the design process
   c. Payback period can be extended with an early start
   d. Complicated coordination can be carried out over a longer period of time

C is the correct answer - payback period is not begun until equipment is paid for; and a shorter *payback period is preferable.*

7. Which of the following is unlikely to be affected by site selection factors?
   a. <u>Utility connection cost</u>
   b. Stormwater management strategies
   c. On-site solar power generation
   d. Landscaping requirements

A is likely to be the same throughout a region for a given building. B can be effected by topography and soil conditions. C can be effected by surrounding natural and constructed features that may block solar access for some areas. D is dependent on the existing site

8. Energy modeling provides which?
   a. <u>Comparative information that allows the designer to better understand trade-offs.</u>
   b. Definitive information about the building's future energy bills.
   c. Vital information about plug loads and energy use by the building's occupants
   d. Speculative information about the lifetime energy use by the building.

A is correct. B and D - energy models are not for predicting specific costs. C - these are likely to be variable over time, and are not the types of information energy models focus on comparing alternatives for.

9. Stormwater control is best done
   a. <u>On the building site, to recharge the underground water table</u>
   b. By quickly moving surface water to nearby storm drains
   c. By preventing water from soaking into the ground
   d. With central processing plants to filter contaminants

A is correct. B is very much to be avoided as much as possible. C and D - both of these are the opposite of the intent.

10. Adaptive reuse can provide what added benefit?
    a. <u>Preserve existing neighborhood character for the present community.</u>
    b. Reduces energy use in the building.
    c. More natural materials are already present.
    d. Better on-site stormwater management with existing structures.

A is correct. B - working with an older building envelope is seldom more energy efficient than well done contemporary construction. C - may be true in some cases, but this is not the principal benefit. D - this is seldom true, and storm structures are not the preferred option.

11. Energy used to transport people and goods to a building...
    a. <u>Should be considered as part of the total energy required for operating the building.</u>
    b. Will reduce the LEED score for a building located in a dense urban setting.
    c. Can be offset by installing rooftop solar panels
    d. Does not matter, since it happens off-site.

A is correct. B and C - these issues are not connected to transport energy use. D - this statement is counter to sustainable principles.

12. Which of the following is <u>**not**</u> true about passive solar ?
    a. Once incorporated into a building, passive solar has very little or no operating cost.
    b. Solar angles are regular and predictable, allowing effective incorporation into the design.
    c. <u>Where mechanical systems are required, there is no benefit in using passive solar principles.</u>

d. Shading is also important in designing for passive solar.

C is the correct answer; passive solar may be able to contribute even if the building ha mechanical heating systems.

13. Reducing water consumption with efficient fixtures also supports which positive synergy?
    a. Reducing water consumption also reduces energy use for water heating
    b. The building requires less dehumidification equipment, which is very costly
    c. The interior air quality is improved
    d. Gray water systems can be used

A is correct. B - interior humidity is not tied to fixture efficiency. C - indoor air quality is not tied to fixture efficiency. D - gray water are not reliant on efficient fixtures.

14. When evaluating the options between all-electric or some fossil systems for a building, which of the following is true?
    a. The option that provides the highest LEED score should be used
    b. It doesn't matter, because electricity is generated by burning fossil fuels
    c. Reduction of carbon emissions should be the driving consideration
    d. Fossil fueled systems are clearly preferred because they are cheaper

C is correct. A - LEED points may be desirable, but are a secondary concern. B - the generating fleet is becoming less reliant on fossil fuels, and will become a better option over time. D - may be cheaper, but this is not the sustainable choice.

15. Maintenance is important for the ongoing sustainability of a building for all of the following reasons except which?
    a. Operational efficiency is retained and reduced carbon emissions are limited when equipment is in proper operating condition.
    b. Equipment that is maintained in good condition will continue to operate longer, thereby extending its working life and reducing cost and the need for replacements.
    c. If not properly maintained and operated, functions that the building was designed for may not be properly supplied
    d. Maintenance costs can be avoided by buying more expensive systems that will last longer.

D is the correct answer.

16. Energy efficiency for a sustainable building is...
    a. The number one goal for any sustainable building.
    b. An important part of reducing carbon footprint and operational cost
    c. Less important if a building uses extensive on-site renewable power generation.
    d. Always a trade-off with building comfort

B is correct. A - can be an important feature for may buildings, but is not always the highest priority. C - energy efficiency is even more important with on-site generation in order to help keep the size of that system smaller. D - very comfortable and energy efficient buildings are very possible

17. What is the greatest benefit of using US Green Building Council LEED during the design of a building?
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d. Measures the efficiency and carbon footprint of the building

C is correct. A - adaptive reuse is a small part of LEED, even where it is applicable. B - LEED does nothing to prevent any equipment from being used. D - LEED does not measure aspects of a building like this.

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