DESIGNING TO MEET CLIMATE CHANGE CHALLENGES

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Abstract:

We identify decision points in standard engineering work processes where adjustments should be made to assist design teams to evaluate climate change related design impacts. Early in the project, design options should be evaluated to optimize the combined greenhouse gas (GHG) reduction benefits of interfacing building systems. In the conceptual design stage, GHG emission reducing alternatives can be evaluated and incorporated into the design. In addition, sustainable GHG reducing engineering, procurement and construction approaches should be evaluated and adopted early in the project for cross-functional benefits to the project and to the client

In the preliminary engineering phase emission monitoring and control of greenhouse gases may be considered. Closed-loop processes may also be considered to minimize potable water use and wastewater generated. In this design phase, future site climatic conditions should be considered, in addition to developing criteria based on historical norms. In the final design phase, when specifications and material requisitions are developed, they should include GHG reducing requirements for high performance building systems including: energy efficient HVAC, lighting and building envelope systems; water conserving utility systems and processes; recycled or rapidly renewable materials content; and fuel efficiency standards for construction site vehicles.

Keywords:

climate change, adaptation, mitigation, sustainable design, greenhouse gases, standard engineering work processes, emissions, carbon dioxide, global warming

1 Introduction

Growing and potential impacts of climate change (Karl *et al* [1]), such as flooding in coastal areas, change in weather patterns, and melting of the permafrost have created new challenges for the engineering and construction industry. These challenges involve adaptation in the design and construction of projects to address these impacts, as well as developing ways to reduce and controlling greenhouse gas (GHG) emissions to mitigate climate change.

Engineering has the lead responsibility for determining the technical feasibility and cost parameters to overcome these challenges. Engineering and construction projects are implemented with the help of a set of standard documents that lay out the work process of the projects. They include standard design detail drawings, standard design criteria, standard specifications, design guides and work process flow diagrams. Incorporating in these standard documents materials and processes which assist project engineers to identify and assess climate change related impacts can be a major step in effectively preparing to meet the challenges of climate change mitigation and adaptation.

2 Optimizing the Design Process

In many respects designing to meet climate change challenges is sustainable design. A project execution approach integrating the following concepts for sustainable engineering, procurement and construction (S-EPC) is directly relevant to designing for climate change:

- Site master planning and design for ecology

- Potable water conservation, and minimizing waste water discharges
- Process design to conserve water, energy and other natural resources
- Design provisions for phased construction to meet current needs with provisions for meeting future facility requirements; provisions for adding sustainable design measures in future phases of construction, if not funded in the initial phase
- Passive design of facilities to save energy in plant and building operations, e.g. Energy Star® roofs or green (vegetated) roofs; adequate insulation of building walls, roofs, pipes, ducts and vessels, to minimize fossil-fueled power consumption and emissions
- High-efficiency HVAC and electrical systems including high-performance lighting systems integrated with daylighting and smart controls
- Energy Star® appliances and equipment
- Onsite renewable energy with energy storage for peak use, meeting the power demand that has been reduced by all of the above concepts, and resulting in reduced fossil fuel demand / emissions.
- Eco-purchasing and contracting: "greening" the supply chain to minimize climate change impacts of the supply chain.
- Managed construction to protect the site's natural resources, minimize pollution and waste and recycle or salvage surplus materials.
- Neutralizing any additional capital costs by combining "hard" benefits (life-cycle cost savings and returns on investment) with "soft" benefits (intangible but real and significant).

Similarly formulated sustainable design concepts can be found as the Hannover principles (William McDonough & Partners [2]), the Twelve principles of green engineering (Anastas and Zimmerman [3]) and ten tenets of structural sustainability (D'Aloisio [4]).

Designs informed by an integration of these concepts, with inter-discipline and cross-functional trade-offs for overall optimization of the project, are more energy efficient, minimize GHG emissions and adapted to a changing climate. They add value to the standard engineering work execution by better integrating the design of systems. The combined benefit of the overall optimization is greater than if the systems are optimized individually. The benefits include significant reductions in energy and water requirements leading to lower GHG emissions and resulting in cost savings in construction and facility operations, as well as reduced impact on the site and the environment.

To implement sustainable design, the standard engineering work process needs to be enhanced to foster closer collaboration among disciplines and functions. For cost-effective success, sustainable design should be embedded as an integral part of the engineering work process. Designing to meet climate change challenges does not have to be an "add-on" to the current work process. Figure 1 provides an overview of the standard work process with some notes on sustainable design related activities that can be integrated into the standard process.

3 Conceptual Design

The conceptual design phase is when sustainable design, climate change mitigation and adaptation features can be most easily incorporated into a project. Establish a multi-disciplinary team of project personnel and hold an integrated sustainable design team planning meeting early in project development. This integrated team does more than coordinate; it collaborates throughout all project phases and includes engineering, procurement, construction, the client, operator and other stakeholders. The team can be established as an integrated project team following U.S. Department of Energy (U.S. DOE [5]) or U.S. Department of Defense (U.S. DOD [6]) or similar guidelines.

This group should establish sustainability and GHG emission performance goals: e.g., 25-percent less energy use than required by code, 30-percent reduction in GHG emissions relative to a baseline facility providing the same products or services. The team should document the goals in the project execution plan and/or relevant discipline engineering design criteria.

The integrated design team ensures collaborative work among all disciplines to embed sustainable design concepts, sustainable systems, green fabrication and construction techniques into the development of the project design and systems selection. It helps the project team evaluate alternatives to optimize the overall systems / process / facility design and realize the benefits of sustainable design.

Expertise in sustainable design methods, including energy modeling and building information modeling, may or may not be available "on-project". Depending on the project and scope of sustainable design, experts in energy modeling, wetland design, stormwater management, energy-efficient lighting should be made available to the project from off-project staff or consultants, as needed. Accreditation by the U.S. Green Building Council for LEED™ is highly desirable for members of the integrated design team.

Table 1 provides examples of climate change related sustainable design performance metrics that can be used to establish these goals. A broader set of metrics is available from the Institution of Chemical Engineers (IChemE). The Leadership and Energy and Environmental Design (LEED™) building rating system also provides a framework for setting project performance goals

Table 2 provides a list of GHGs associated with specific industrial sectors. Table 3 provides the major emission categories, with a representative list of devices that fall into each of these categories.

During conceptual design, the integrated sustainable design team evaluates design alternatives. Project facilities, process and mechanical equipment, and building components or features should be evaluated based on their sustainability as well as feasibility and cost-effectiveness. The team should consider the maturity of the technology of the building, facility or process feature; the capital expenditure (i.e., first cost) required to procure, install, and implement the facility, building or process feature under consideration; the acceptable time horizon to repay the initial capital expenditure through savings made via operating and maintenance costs over the life of the feature; and the carbon emitted during the construction and operation of the facility, building or process feature.

Consider alternatives to:

- Maximize energy efficiency and minimize GHG emissions by:
    - Selection of a suitable location and orientation for the facilities on the site and their configurations and proportions to minimize energy loads (and thus GHG emissions) on the building due to climate at the site and to take advantage of passive solar and wind opportunities
    - Preservation of natural site features, restoration of degraded habitat areas, and minimize facility footprint to preserve the maximum open space and undisturbed land
    - Providing for natural daylighting, renewable energy, and natural ventilation
    - Selecting high-efficiency HVAC systems that exceed ASHRAE 90.1 requirements (ANSI/ASHRAE [7])
    - Providing light-colored roofing to reflect light and heat
    - Sealing joints and airlocks prior to sizing mechanical conditioning systems to avoid over-sizing equipment
    - Reclaiming waste heat from equipment and return air and water
    - Installing vegetated rooftops
    - Maximizing the efficiency of electric power distribution; size transformers close to the actual anticipated load; distribute power at the highest practical voltage at the maximum power factor
    - Maximizing service water heating and cooling efficiency, and considering solar hot water heating
- Maximize water efficiency by:
    - Collection and reuse of rainwater

- Closed-loop processes to conserve water and other resources
- Alternative wastewater treatment system selection. Consider waste water from processes for possible treatment and reuse as grey water, if permitted.
- Developing self-sustaining landscapes using native plants tolerant of soils, climate, and drought with minimal irrigation using harvested rainwater or grey water
- Specifying water-efficient plumbing such as ultra-low-flow or waterless plumbing
- Protect or restore the existing site hydrology

• Minimize the embodied energy and carbon content of materials by
  - Considering off-site pre-fabrication to minimize onsite cutting and waste.
  - Designing for constructability and potential reuse
  - Develop energy and emissions criteria to include in materials requisitions

The conceptual design should include development of a simplified energy model, a preliminary estimate of GHG emissions and embodied carbon content, a preliminary lifecycle cost estimate and a 3-D model with preliminary building information. These design documents and models are used throughout the design process to assess progress toward meeting the sustainable design goals. Upon completion of these and other design deliverables, conduct the first review of the sustainable design aspects of the project during the project's first design review. This review should check that the sustainability goals established earlier, including energy efficiency, GHG emissions, water efficiency and materials content are being met. The National Renewable Energy Laboratory has a handbook for planning and conducting charrettes for high-performance projects that may be helpful in preparing for the sustainable design portion of the design review (NREL [8]).

Compare preliminary energy model results with sustainable design performance benchmarks, using readily available software for: energy requirements simulation; renewable energy; water conservation; and lighting and daylighting analysis.

GHG emissions may be estimated for sources classified according to a scheme similar to that provided on Table 3 for the petroleum industry (API [9]). Table 3 provides the major emission categories, with a representative list of devices that fall into each of these categories. The GHG Protocol for Project Accounting developed by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI/WBCSD [10]) appears to be the protocol most suitable for use developing design basis GHG emissions estimates. The U.S. Energy Information Administration provides emissions coefficients for a number of fuels combusted for energy generation here: www.eia.doe.gov/oiaf/1605/coefficients.html (last accessed 30 Aug 2010).

Useful guides to life-cycle cost estimates are provided by ASTM International and the U.S. Department of Energy. ASTM E 917-05 is a standard practice for measuring life-cycle costs of building and buildings systems (ASTM International [11]). The U.S. DOE's guidance is for life-cycle cost analyses required by Executive Order 13123, Greening the Government through Efficient Energy Management (U.S. DOE [12]).

A number of resources are available to check the embodied energy and carbon content of materials. The University of Bath, Department of Mechanical Engineering, maintains a database of the embodied carbon dioxide and energy content of building materials. A summary of the coefficients in the database is periodically published and is available here: www.bath.ac.uk/mech-eng/sert/embodied/ (last accessed 30 Aug 2010). The embodied energy and carbon dioxide refers to the total primary energy consumed and carbon dioxide released over the life-cycle of the construction material. With the life-cycle boundary being defined as all energy and carbon dioxide emissions from the extraction of raw materials through manufacturing up to the point where the materials leave the manufacturing facility.

4 Preliminary Design

During preliminary design develop the facility energy model to confirm the design meets the established performance goals; calculate facility operations GHG emissions and materials embodied carbon content; develop a facility life-cycle cost estimate; include building information in the 3-D model. Periodically update these calculations and verify the project continues to meet the sustainable design performance goals as design progresses.

Continue to promote an integrated work process among all disciplines with early inputs from procurement, project controls and construction to assure continued implementation of the established sustainable design scope during systems selection. The following tasks are included in this design phase:

- Include sustainable engineering concepts in system design descriptions and facility design descriptions. Right-size systems and facilities using software models (not conventional rules-of-thumb), avoid over-design.
- Identify energy consumption by category, e.g., internal loads from the processes, building envelope loads (heat losses / gains through walls, roofs, etc.), ventilation requirements, and others.
- Identify energy interactions between systems and opportunities for reductions in energy requirements and cost savings through energy efficiency measures.
- Develop alternative design solutions to reduce energy loads and evaluate systems as a whole.
- Iterate these optimization steps and refine the system selection / design to arrive at the optimized combination of systems for energy efficiency and emissions reduction.
- Update the energy model, emissions calculations, cost estimate and 3-D model to reflect the design, as it develops.

Conduct a second review of progress toward meeting energy and emissions goals on the project, after the design concept is developed. This review can be concurrent with other required design reviews and is intended to confirm continued progress toward meeting the established sustainable design criteria.

5 Detailed Design

Continue to promote an integrated work process among all disciplines to assure continued implementation of the established energy efficiency and emissions reduction goals. Specify low embodied CO_2 and energy content materials. Include embodied energy and CO_2 evaluation criteria in technical bid evaluations. Specify materials available locally.

Develop a construction execution strategy that minimizes construction energy consumption and greenhouse gas emissions. Consider construction waste management options, construction vehicle options, etc.

Finalize the:

- Energy model
- 3-D model with building information
- GHG emissions calculations
- Life-cycle cost estimate

Conduct a third and final review of the design relative to the energy efficiency and emissions reduction goals.

Assist procurement with evaluating and pre-qualifying potential bidders for materials, systems and sources to support implementation of sustainable design goals. Discuss sustainable design requirements in pre-bid meetings. Include criteria for vendors to conserve energy, water and other natural resources during field construction activities.

Incorporate sustainable design requirements in standard project specifications and material requisitions (MRs) to be included with purchase orders and contracts / sub-contracts, including sourcing from suppliers practicing sustainable manufacturing practices, which are located near the construction site.

6 Construction

Prepare a site master plan for orderly development of infrastructure and land use on the site for the construction phase and operations phase. Prepare designs and specifications for temporary field facilities following sustainable design principles. Locate temporary facilities in non-sensitive areas of the site and minimize temporary facilities by building permanent facilities early in the construction phase and using them for construction needs. Include sustainable engineering considerations in responses to requests for information, field change requests and other design change documents.

During construction, track embodied energy and CO_2 content of construction materials; review supplier submittals and substitutions for impacts on energy and emissions performance goals. Review field change requests for impacts on energy and emissions performance goals and plan for energy and emissions systems commissioning to verify performance during operation. Commissioning activities may begin as early as the conceptual design phase when the commissioning agent reviews design documents for conformance with the sustainable design criteria. During construction and start-up the commissioning agent verifies installation of energy and emissions related systems and confirms that they operate as specified.

7 Conclusions

Designing to meet the challenges of climate change does not require a completely new design process. Incorporating sustainable design considerations into the conventional design process can result in more energy efficient and lower GHG emitting designs if sustainable design performance goals are set early in the project development and regularly monitored to assure the evolving design continues to support achieving the goals. Establishing an integrated sustainable design project team comprised of representatives from each engineering discipline, procurement, construction, the client and other stakeholders provides a working group to collaborate in evaluating design alternatives to optimize energy efficiency and minimize emissions.

This integrated team develops sustainable design criteria early in the project, is involved in developing and maintaining an energy model and 3-D model with building information. The team track GHG emissions and the embodied carbon and energy contents of materials by periodically updating relevant design calculations. The team participates in development and periodic updates of the project life-cycle cost estimate to inform decisions about the feasibility of implementing sustainable design alternatives.

All of these activities can be conducted in the context of an established design process and provide added value to clients in terms of energy and water efficiency. While it may not be possible to fully embed sustainable design in the standard engineering work process without some cost and potentially schedule consequences for engineering, it is likely that when considered in the context of the overall life-cycle cost of a project, sustainable design will reduce life-cycle costs and produce significant benefits for climate change mitigation.

References

1. Karl, T.R, Melillo J.M., and Peterson T.C., (eds); 2009; Global Climate Change Impacts in the United States; Cambridge University Press.
2. William McDonough & Partners, 1992; The Hannover Principles, Design for Sustainability; Prepared for EXPO 2000 The World's Fair; Hannover, Germany.
3. Anastas, P.T. and Zimmerman, J.; Design through the 12 Principles of Green Engineering; Environmental Science & Technology, March 1, 2003.
4. D'Aloisio, J.A., 2007; Sustainable Design: Ten tenets of structural sustainability; Structural Engineering, June 2007, pg 16.
5. U.S. Department of Energy(U.S. DOE), 2003; Project Management Practices, Integrated Project Teams; June 2003.
6. U.S. Department of Defense (U.S. DOD, 1998; DoD Integrated Project and Process Development Handbook, Office of the Under Secretary of Defense, August 1998.
7. American National Standards Institute (ANSI)/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1; Energy Standard for buildings Except Low-Rise Residential Buildings; American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
8. National Renewable Energy Laboratory (NREL), 2003; A Handbook for Planning and Conducting Charrettes for High-Performance Projects, NREL/BK-710-33425; August 2003.
9. American Petroleum Institute (API), 2004; Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry, (http://www.api.org/ehs/climate/new/upload/2004_COMPENDIUM.pdf, last accessed 30 Aug 2010).
10. World Resource Institute (WRI) and World Business Council on Sustainable Development (WBCSD), 2005; The Greenhouse Gas Protocol for Project Accounting (http://www.ghgprotocol.org/standards/project-protocol, last accessed 30 Aug 2010).
11. ASTM International, 2005; ASTM E 917-5, Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, 2005.
12. U.S. Department of Energy (U.S. DOE), 2005; Guidance on Life-Cycle Cost Analysis Required by Executive Order 13123, April 2005.

Table 1. *Climate Change Related Project Performance Metrics*

Category	**Metric**
Materials	Materials used by weight (kg) or volume (m^3)
	Weight or volume percentage of materials used that have recycled input materials
	Total weight of waste materials by type and disposal method
Energy	Direct energy consumption (kJ) by primary energy sources
	Indirect energy consumption (kJ) by primary source
	Energy exports (kJ)
	Energy use per weight or volume of product produced (kJ/kg or kJ/m^3)
Water	Total water withdrawal by source (m^3)
	Total water discharges by quality and destination (m^3)
Emissions	Total direct and indirect greenhouse gas emissions by weight (tons CO_2-equivalents)
	Indirect greenhouse gas emissions by weight (tons CO_2-equivalents)
	Greenhouse gas emissions per weight or volume of product produced (tons CO_2-equivalents/kg)
	Emissions of ozone-depleting substances by weight (kg)
	Emissions of NO_x, SO_x, PM_{10}, ozone, carbon monoxide and lead by weight (kg)
	Emissions avoided (kg)

Table 2. *Industry Specific Greenhouse Gases as Identified in 2006 IPCC Guidelines for National Greenhouse Gas Inventories*

Industry	Activity	Greenhouse Gases
Power	Fuel combustion	CO_2, CH_4, N_2O, NO_x, CO, NMVOC, SO_2
	Fugitive emissions from fuel	CO_2, CH_4, N_2O, NO_x, CO, NMVOC
Mining & metals	Industrial processes and product use	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, Other halogenated gases, NO_x, CO, NMVOC, SO_2
	Metals industry	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, Other halogenated gases, NO_x, CO, NMVOC, SO_2
Oil, gas and chemicals	Industrial process and product use	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, Other halogenated gases, NO_x, CO, NMVOC, SO_2
	Chemical industry	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, Other halogenated gases, NO_x, CO, NMVOC, SO_2
Other	Waste	CO_2, CH_4, N_2O, NO_x, CO, NMVOC, SO_2

NMVOC: non-methane volatile organic compounds

Table 3. *Source Classifications*

Category	**Principal Sources Include:**
Combustion Devices	
Stationary Devices	Boilers, heaters, furnaces, reciprocating internal combustion engines and turbines, flares, incinerators, and thermal/catalytic oxidizers
Essential Mobile Sources	Barges, ships, railcars, and trucks for material transport; and planes/helicopters and other company vehicles
Indirect	Off-site generation of electricity, hot water and steam for onsite power and heat
Vented Sources	
Process Vents	Hydrogen plants, amine units, glycol dehydrators, fluid catalytic cracking unit and reformer regeneration, flexicoker coke burn
Other Venting	Crude oil, condensate, and petroleum product storage tanks, gas-driven pneumatic devices, chemical injection pumps, exploratory drilling, loading/ballasting/transit, loading racks
Maintenance/Turnaround	Decoking of furnace tubes, vessel and gas compressor depressurizing, well and pipeline blowdowns, tank cleaning, painting
Non-Routine Activities	Pressure relief valves, emergency shut-down devices
Fugitive Sources	
Fugitive Emissions	Valves, flanges, connectors, pumps, compressor seal leaks
Other Non-Point Sources	Wastewater treatment, surface impoundments

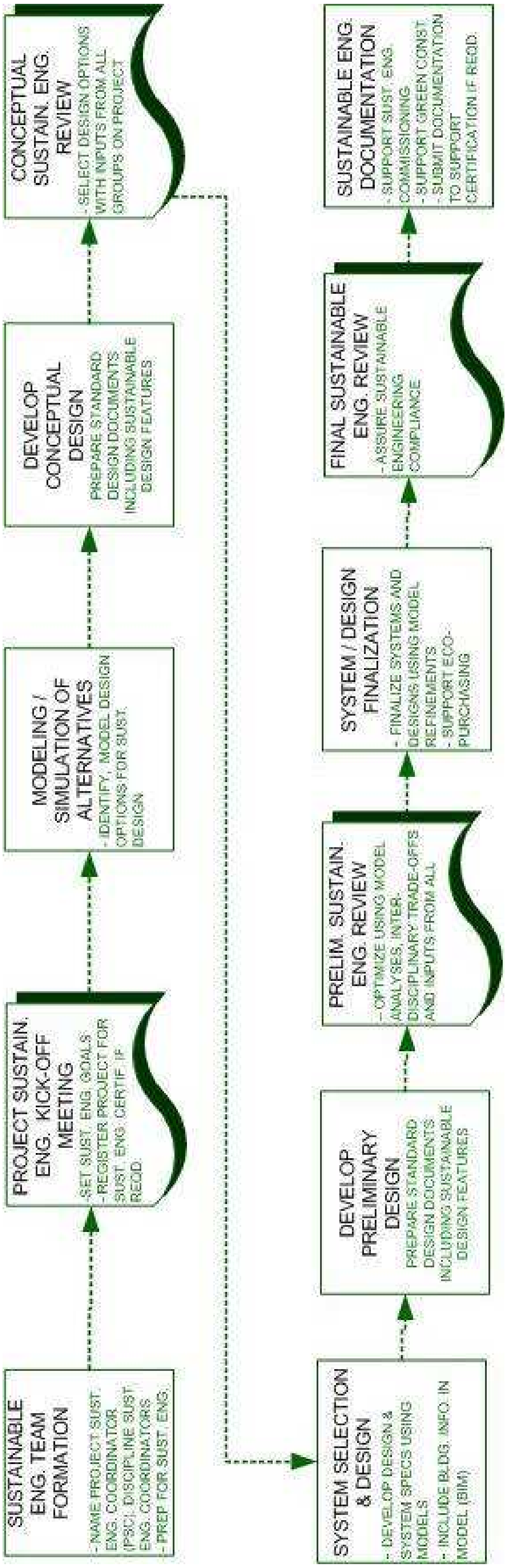

Figure 1. *Overview of Design Work Process with Sustainable Design Elements Embedded*