# How Do I Write a Sustainable Concrete Specification?

Donn C. Thompson AIA, LEED AP BD+C
National Ready Mixed Concrete Association

NRMCA

SUSTAINABLE STRUCTURES WEBINAR SERIES

1

## About the Course

**Learning Units**

- AIA-CES SSC-101 (1LU/HSW - 1 PDH - 0.1 CEU)

**Learning Objectives**

- Understand the difference between performance-based specification and prescriptive specifications
- Discover how performance-based specifications can improve performance and lower environmental impacts of concrete structures.
- Learn how to implement performance-based specifications in projects.
- Demonstrate the importance of balancing structural and architectural performance of concrete with green building strategies.

2

## Is Concrete Sustainable?


3

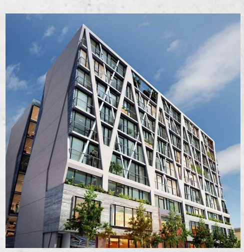
## Influence of Design Decisions

- Energy efficiency
- Resilience
- Aesthetics
- Structural efficiency
- Cost
- Others?

4

## Case Study: Rowan, San Francisco

- Zigzagging concrete exoskeleton
- Stands out from other buildings
- Negates the need for interior columns
- Maximizing the interior space for residents
- Concrete on the project used high volumes of fly ash to reduce environmental footprint



5

## Is This Concrete Sustainable?

**50% portland cement replacement!**
**Is this Sustainable Concrete?**

| | |
|---|---|
| Portland cement | 208 kg/m³ ([illegible] lb/yd³) |
| Slag cement | 178 kg/m³ (300 lb/yd³) |
| Silica fume | [illegible] kg/m³ (50 lb/yd³) |
| Coarse aggregate | [illegible]068 kg/m³ (1800 lb/yd³) |
| Fine aggregate | 712 kg/m³ (1200 lb/yd³) |
| Water | 178 kg/m³ (300 lb/yd³) |
| Air content | 6% |

Not Sure

6

## High Early Strength Concrete

7

## Mass Concrete

8

## To Be Sustainable, Concrete Needs To:

- Meet traditional performance requirements of the owner, designers, contractor and producer

**+**

- Minimize Energy Consumption and $CO_2$ Footprint
- Minimize Potable Water Use
- Minimize Waste
- Increase Use of Recycled Content

9

## Case Study: Denver International Hotel and Transit Center

- Complex mix designs
  - High strength concrete
  - Self-consolidating concrete
  - Lightweight concrete
- Complex structural systems
  - Ballroom's transfer beams
  - Sloping roof deck
  - Architecturally exposed concrete
  - Clean and attractive finish
- Selected concrete
  - Fire resistance
  - Strength

10

## Influence of Project Specifications

- Sustainability criteria should have minimum impact on performance or service life of concrete
- Specifications should not restrict concrete from being sustainable

11

## Concrete Performance

- Performance of concrete materials are based on performance indicators measured by standard test methods with defined acceptance criteria stated in contract documents and with no restrictions on the parameters of concrete mixture proportions

12

## Performance Based Specification

- Specifier defines performance requirements
- Consider qualifications of concrete producer and contractor
- Producer and contractor ensure right mixture is designed, delivered and installed
- Submittals include pre-qualification tests
- Field acceptance tests determine if concrete meets performance criteria
  - Not all tests are conducive to field testing
- Instructions outlining what happens when concrete does not meet performance criteria

13

## Problems with Prescriptive Specifications

- Does not assure required performance
- Prevents mixtures from being optimized
- No incentive
  - Quality
  - Innovation
- Contradicts sustainability initiatives
- Responsibility is unclear

14

## Most Common Prescriptive Requirements

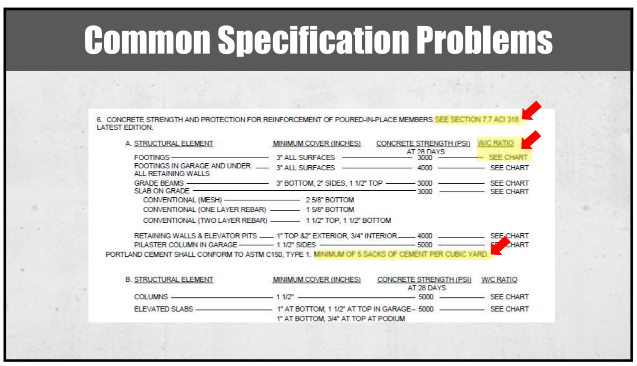
| Prescriptive Requirement | Frequency Seen |
|---|---|
| Restriction on SCM quantity | 85% |
| Max w/cm (when not applicable) | 73% |
| Minimum cementitious content | 46% |
| Restriction on SCM type, characteristics | 27% |
| Restriction on aggregate grading | 25% |

15

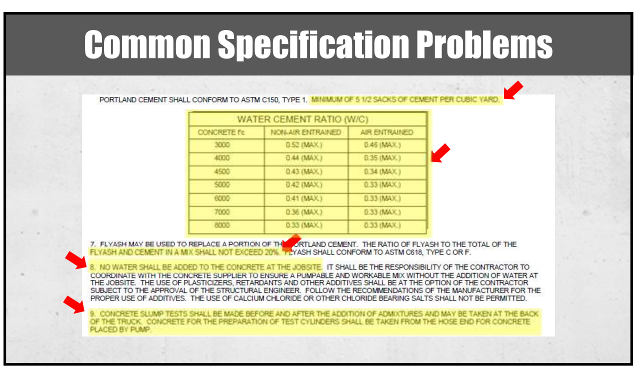
15


References
Prescriptive Specifications
A reality check
ACI Concrete International Aug 2015
Specification in Practice
What, why & how?
nrmca.org/p2p
structural SPECIFICATIONS
Specifying Requirements for Concrete Mixtures
STRUCTURE Magazine, April 2019
www.structuremag.org
16

16


Common Specification Problems
6. CONCRETE STRENGTH AND PROTECTION FOR REINFORCEMENT OF POURED-IN-PLACE MEMBERS; SEE SECTION 7.7 ACI 318 LATEST EDITION.
A. STRUCTURAL ELEMENT — MINIMUM COVER (INCHES) — CONCRETE STRENGTH (PSI) AT 28 DAYS — W/C RATIO
FOOTINGS — 3" ALL SURFACES — 3000 — SEE CHART
FOOTINGS IN GARAGE AND UNDER ALL RETAINING WALLS — 3" ALL SURFACES — 4000 — SEE CHART
GRADE BEAMS — 3" BOTTOM, 2" SIDES, 1 1/2" TOP — 3000 — SEE CHART
SLAB ON GRADE — 3000 — SEE CHART
CONVENTIONAL (MESH) — 2 5/8" BOTTOM
CONVENTIONAL (ONE LAYER REBAR) — 1 5/8" BOTTOM
CONVENTIONAL (TWO LAYER REBAR) — 1 1/2" TOP, 1 1/2" BOTTOM
RETAINING WALLS & ELEVATOR PITS — 1" TOP &2" EXTERIOR, 3/4" INTERIOR — 4000 — SEE CHART
PILASTER COLUMN IN GARAGE — 1 1/2" SIDES — 5000 — SEE CHART
PORTLAND CEMENT SHALL CONFORM TO ASTM C150, TYPE 1. MINIMUM OF 5 SACKS OF CEMENT PER CUBIC YARD.
B. STRUCTURAL ELEMENT — MINIMUM COVER (INCHES) — CONCRETE STRENGTH (PSI) AT 28 DAYS — W/C RATIO
COLUMNS — 1 1/2" — 5000 — SEE CHART
ELEVATED SLABS — 1" AT BOTTOM, 1 1/2" AT TOP IN GARAGE — 5000 — SEE CHART
1" AT BOTTOM, 3/4" AT TOP AT PODIUM

17


Common Specification Problems
PORTLAND CEMENT SHALL CONFORM TO ASTM C150, TYPE 1. MINIMUM OF 5 1/2 SACKS OF CEMENT PER CUBIC YARD.
WATER CEMENT RATIO (W/C)
CONCRETE f'c — NON-AIR ENTRAINED — AIR ENTRAINED
3000 — 0.52 (MAX.) — 0.46 (MAX.)
4000 — 0.44 (MAX.) — 0.35 (MAX.)
4500 — 0.43 (MAX.) — 0.34 (MAX.)
5000 — 0.42 (MAX.) — 0.33 (MAX.)
6000 — 0.41 (MAX.) — 0.33 (MAX.)
7000 — 0.36 (MAX.) — 0.33 (MAX.)
8000 — 0.33 (MAX.) — 0.33 (MAX.)
7. FLYASH MAY BE USED TO REPLACE A PORTION OF THE PORTLAND CEMENT. THE RATIO OF FLYASH TO THE TOTAL OF THE FLYASH AND CEMENT IN A MIX SHALL NOT EXCEED 20%. FLYASH SHALL CONFORM TO ASTM C618, TYPE C OR F.
8. NO WATER SHALL BE ADDED TO THE CONCRETE AT THE JOBSITE. IT SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR TO COORDINATE WITH THE CONCRETE SUPPLIER TO ENSURE A PUMPABLE AND WORKABLE MIX WITHOUT THE ADDITION OF WATER AT THE JOBSITE. THE USE OF PLASTICIZERS, RETARDANTS AND OTHER ADDITIVES SHALL BE AT THE OPTION OF THE CONTRACTOR SUBJECT TO THE APPROVAL OF THE STRUCTURAL ENGINEER. FOLLOW THE RECOMMENDATIONS OF THE MANUFACTURER FOR THE PROPER USE OF ADDITIVES. THE USE OF CALCIUM CHLORIDE OR OTHER CHLORIDE BEARING SALTS SHALL NOT BE PERMITTED.
9. CONCRETE SLUMP TESTS SHALL BE MADE BEFORE AND AFTER THE ADDITION OF ADMIXTURES AND MAY BE TAKEN AT THE BACK OF THE TRUCK. CONCRETE FOR THE PREPARATION OF TEST CYLINDERS SHALL BE TAKEN FROM THE HOSE END FOR CONCRETE PLACED BY PUMP.

18

## Example Specification (Hybrid)

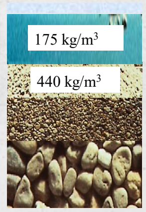
Interior Building Column

- Maximum w/cm = 0.40
- Min. Cem. Matls. = 640 lb/yd$^3$ (380 kg/m$^3$)
- Maximum fly ash = 15% by mass of CM
- Specified strength $f'_c$ = 4000 psi (28 MPa)
- Max. Slump = 4 in. (100 mm)

19

## Solution 1 - prescriptive

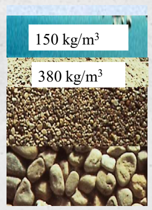
- Start with water – 295 lb/yd$^3$
- w/cm 0.40
- CM - 740 lb/yd$^3$
- Strength = 7000 psi (48 MPa)
  - Specified = 4000 psi (28 MPa)
- Paste volume = 31%
  - High heat of hydration
  - High shrinkage
  - High creep




20

## Solution 2 - prescriptive

- Start with CM – 640 lb/yd$^3$
- w/cm 0.40
- Water - 250 lb/yd$^3$ + HRWRA
- Strength = 6500 psi (44 MPa)
  - Specified = 28 MPa
- Paste volume = 27%
  - Placing?
  - Finishing – sticky?




21

## Solution 3 - performance

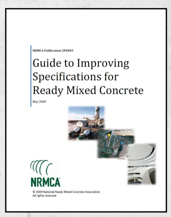
- Target strength
  - 5500 psi (32 MPa) 28 days
  - 2500 psi (17 MPa) 3 days
  - Self consolidating concrete
- Concrete mixture
  - CM 460 lb/yd$^3$ (270 kg/m$^3$), 25% fly ash
  - w/cm = 0.45
  - Optimized aggregates
  - Admixtures for SCC
- Paste volume = optimized for SCC - placement
  - Improved aesthetics and performance

22

## Performance Specifications

**General Guidelines**

- Do not limit material ingredients that are permitted in standards
- Do not try to control means and methods such as early age strength and slump
- Do not limit Global Warming Potential or Carbon Footprint for each mix, but establish a carbon budget for the entire building.
- We will email a PDF copy to all attendees




23

## Specifications and Sustainability

| Specification Provision | Impacts | | |
|---|---|---|---|
| | Sustainability | Performance | Cost |
| Restrictions on Type and source of cement | ↓ | ↕ | ↑ |
| Not permitting cements conforming to ASTM C1157 and ASTM C595 | ↓ | ↔ | ↔ |
| Restriction on cement alkali content | ↓ | ↔ | ↑ |
| Restriction on type and source of aggregates | ↓ | ↔ | ↑ |

24

## Specifications and Sustainability

| Specification Provision | Impacts | | |
|---|---|---|---|
| | Sustainability | Performance | Cost |
| Restrictions on characteristics of aggregates | ↓ | ↔ | ↑ |
| Minimum content for cementitious materials | ↓ | ↕ | ↑ |
| Restriction on quantity of SCM | ↓ | ↓ | ↑ |
| Restriction on type and characteristics of SCM | ↓ | ↓ | ↑ |

25

## Specifications and Sustainability

| Specification Provision | Impacts | | |
|---|---|---|---|
| | Sustainability | Performance | Cost |
| Restriction on type or brands of admixtures | ↔ | ↓ | ↑ |
| Same class of concrete for all members | ↓ | ↔ | ↑ |
| Requiring higher strength than required for design | ↓ | ↔ | ↑ |
| Invoking maximum w/cm when not applicable | ↓ | ↔ | ↑ |

26

## Specifications and Sustainability

| Specification Provision | Impacts | | |
|---|---|---|---|
| | Sustainability | Performance | Cost |
| Requiring a high air content | ↓ | ↓ | ↑ |
| Restricting the use of a test record for submittals | ↓ | ↓ | ↑ |
| Restriction on changing proportions when needed to accommodate material variations and ambient conditions | ↓ | ↓ | ↑ |

27

## Specifications and Sustainability

| Specification Provision | Impacts | | |
|---|---|---|---|
| | Sustainability | Performance | Cost |
| Requirement to use potable water | ↓ | ↕ | ↑ |
| Not permitting recycled aggregates and materials | ↑ | ↕ | ↓ |
| Not requiring accredited testing labs | ↓ | ↔ | ↑ |
| Specific Limitations on Slump | ↓ | ↓ | ↔ |

28

## Concrete Mixture Requirements

| *Application* | *Nominal Max. Aggregate Size** | *Exposure Class** | *f'c** |
|---|---|---|---|
| *Interior slabs and beams* | *19 mm (3/4 in.)* | *F0, S0, P0, C0* | *28 MPa (4,000 psi)* |
| *Interior Columns* | *19 mm (3/4 in).* | *F0, S0, P0, C0* | *35 MPa (5,000 psi)* |
| *Footings* | *38 mm (1-1/2 in.)* | *F0, S1, P0, C1* | *28 MPa (4,000 psi)* |
| *Exterior slabs and beams* | *19 mm (3/4 in.)* | *F3, S0, P0, C1* | *35 MPa (5,000 psi)* |

- Specify strength at age (more than 28 days)
- Specify Exposure Class (ACI 318)
- Additional criteria (permeability, shrinkage, etc.)

29

## Plant Qualification

- NRMCA Concrete Plant Certification
  - Alternate Approval - DOT
- NRMCA Green-Star Plant Certification (optional)

30

## Personnel Qualification

- NRMCA Certified Concrete Technologist Level 2
- NRMCA Certified Plant Manager
- NRMCA Certified Delivery Professionals

31

## What About Embodied Carbon?

- Do not specify carbon footprint for each mix (application)
- Specify a carbon budget for all the concrete on the project
- Permit more flexibility to meet other performance criteria

32

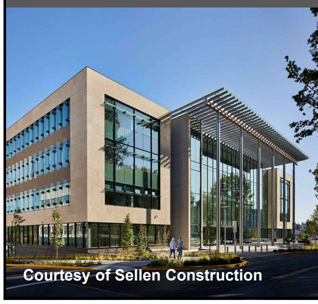
## Product Qualification

- Concrete supplier shall submit Environmental Product Declarations*
- Plant specific EPD is preferred
  - Industry wide EPD (where company is listed) is acceptable

* This requirement should be for all products, not just concrete

33

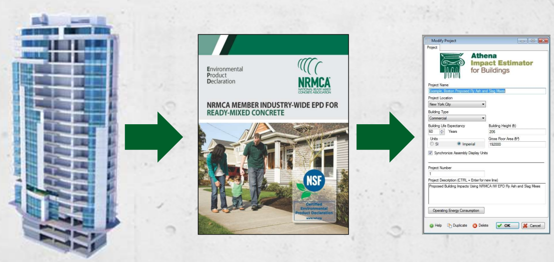
## Case Study: Helen Sommers Building, Olympia, WA




- Five-stories
- 225,000 $ft^2$
- Concrete Frame
- LEED v4 EPD credit
- 50% Slag Mixes
- Saved 1,386 MT of $CO_2$

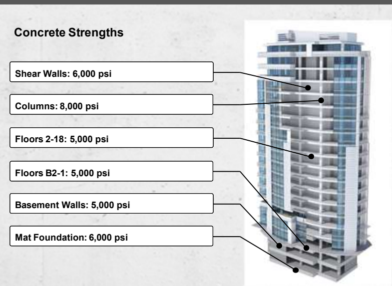
34

## Establishing a Carbon Budget




35

## Example: Proposed Building in Northeast U.S.




36

# NRMCA Industry Wide/Average EPD

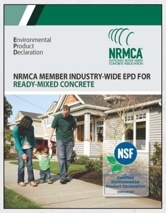



Table 1: Declared Product Range Classification

| Specified Compressive Strength range (Column 1) | SCM range (%) (Column 2) | Product Name (Column 3) |
|---|---|---|
| 0-2500 psi (0-17.24 MPa) | 0-19% Fly Ash and/or Slag | 2500-00-FA/SL |
| | 20-29% Fly Ash | 2500-20-FA |
| | 30-39% Fly Ash | 2500-30-FA |
| | 40-49% Fly Ash | 2500-40-FA |
| | 30-39% Slag | 2500-30-SL |
| | 40-49% Slag | 2500-40-SL |
| | ≥ 50% Slag | 2500-50-SL |
| | ≥ 20% Fly Ash and ≥ 30% Slag | 2500-50-FA/SL |
| 2501-3000 psi (17.25-20.68 MPa) | 0-19% Fly Ash and/or Slag | 3000-00-FA/SL |
| | 20-29% Fly Ash | 3000-20-FA |
| | 30-39% Fly Ash | 3000-30-FA |
| | 40-49% Fly Ash | 3000-40-FA |
| | 30-39% Slag | 3000-30-SL |
| | 40-49% Slag | 3000-40-SL |
| | ≥ 50% Slag | 3000-50-SL |
| | ≥ 20% Fly Ash and ≥ 30% Slag | 3000-50-FA/SL |
| 3001-4000 psi (20.69-27.58 MPa) | 0-19% Fly Ash and/or Slag | 4000-00-FA/SL |
| | 20-29% Fly Ash | 4000-20-FA |
| | 30-39% Fly Ash | 4000-30-FA |
| | 40-49% Fly Ash | 4000-40-FA |
| | 30-39% Slag | 4000-30-SL |
| | 40-49% Slag | 4000-40-SL |
| | ≥ 50% Slag | 4000-50-SL |
| | ≥ 20% Fly Ash and ≥ 30% Slag | 4000-50-FA/SL |

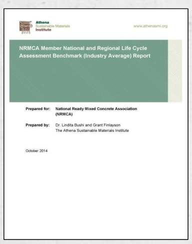
Table 1: Declared Product Range Classification Cont'd

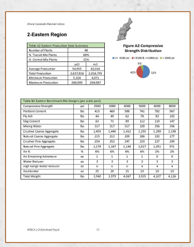
| | | |
|---|---|---|
| 4001-5000 psi (27.59-34.47 MPa) | 0-19% Fly Ash and/or Slag | 5000-00-FA/SL |
| | 20-29% Fly Ash | 5000-20-FA |
| | 30-39% Fly Ash | 5000-30-FA |
| | 40-49% Fly Ash | 5000-40-FA |
| | 30-39% Slag | 5000-30-SL |
| | 40-49% Slag | 5000-40-SL |
| | 50% Slag | 5000-50-SL |
| | ≥ 20% Fly Ash and ≥ 30% Slag | 5000-50-FA/SL |
| 5001-6000 psi (34.48-41.37 MPa) | 0-19% Fly Ash and/or Slag | 6000-00-FA/SL |
| | 20-29% Fly Ash | 6000-20-FA |
| | 30-39% Fly Ash | 6000-30-FA |
| | 40-49% Fly Ash | 6000-40-FA |
| | 30-49% Slag | 6000-30-SL |
| | 40-49% Slag | 6000-40-SL |
| | ≥ 50% Slag | 6000-50-SL |
| | ≥ 20% Fly Ash and ≥ 30% Slag | 6000-50-FA/SL |
| 6001-8000 psi (41.38-55.16 MPa) | 0-19% Fly Ash and/or Slag | 8000-00-FA/SL |
| | 20-29% Fly Ash | 8000-20-FA |
| | 30-39% Fly Ash | 8000-30-FA |
| | 40-49% Fly Ash | 8000-40-FA |
| | 30-49% Slag | 8000-30-SL |
| | 40-49% Slag | 8000-40-SL |
| | ≥ 50% Slag | 8000-50-SL |
| | ≥ 20% Fly Ash and ≥ 30% Slag | 8000-50-FA/SL |

Download at www.nrmca.org/sustainability

37

# NRMCA Eastern Region Benchmark Mixes

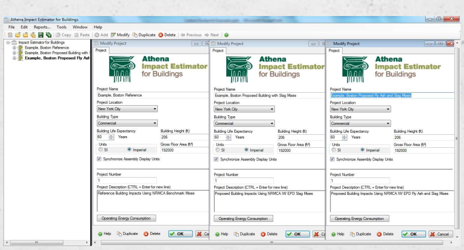




Download at www.nrmca.org/sustainability

38

# Athena Impact Estimator for Buildings



Download at www.athenasmi.org/our-software-data/impact-estimator/

39

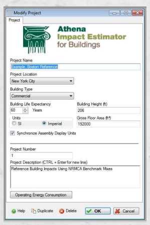
## Estimating Quantities and Properties of Concrete

| Concrete Element | Element Dimensions | Concrete Volume ($yd^3$) | Reference (benchmark) Mixes | Option 1 Proposed Design Mixes (slag) | Option 2 Proposed Design Mixes (fly ash-slag) |
|---|---|---|---|---|---|
| Mat Foundation | 9,600 $ft^2$ x 8' | 2,844 | 6000 psi | 6000 psi 70% slag | 6000 psi 40% slag 30% fly ash |
| Basement Walls | 400' x 24' x 15" | 444 | 5000 psi | 5000 psi 70% slag | 5000 psi 40% slag 30% fly ash |
| Floors B2-1 | 9,600 $ft^2$ x 3 x 12" | 1,067 | 5000 psi | 5000 psi 40% slag | 5000 psi 40% fly ash |
| Floors 2-18 | 9,600 $ft^2$ 17 x 9" | 4,533 | 5000 psi | 5000 psi 30% slag | 5000 psi 30% fly ash |
| Shear Walls | 25' x 40' x 206' x 12" | 7,630 | 6000 psi | 6000 psi 50% slag | 6000 psi 30% slag 20% fly ash |
| Columns | 24" x 24" x 206' x 12 | 366 | 8000 psi | 8000 psi 40% slag | 8000 psi 40% fly ash |

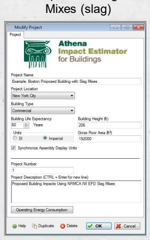
40

## Defining Reference and Proposed Buildings in Athena IE

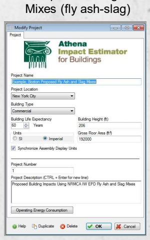
Reference (benchmark) Mixes




Option 1: Proposed Design Mixes (slag)




Option 2: Proposed Design Mixes (fly ash-slag)




41

## Reference Building Impacts

| | | PRODUCT (A1 to A3) | CONSTRUCTION PROCESS (A4 & A5) | USE (B2, B4 & B6) | | | END OF LIFE (C1 to C4) | BEYOND BUILDING LIFE (D) | TOTAL EFFECTS | |
|---|---|---|---|---|---|---|---|---|---|---|
| Summary Measure | Unit | Total | Total | Replacement Total | Operational Energy Use Total | Total | Total | Total | A to C | A to D |
| Global Warming Potential | kg CO2 eq | **6.14E+06** | 2.30E+06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.57E+05 | 0.00E+00 | 8.80E+06 | 8.80E+06 |
| Acidification Potential | kg SO2 eq | 2.42E+04 | 2.29E+04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.24E+03 | 0.00E+00 | 5.13E+04 | 5.13E+04 |
| HH Particulate | kg PM2.5 eq | 6.04E+03 | 1.38E+03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.48E+02 | 0.00E+00 | 7.56E+03 | 7.56E+03 |
| Eutrophication Potential | kg N eq | 2.44E+03 | 1.59E+03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.85E+02 | 0.00E+00 | 4.31E+03 | 4.31E+03 |
| Ozone Depletion Potential | kg CFC-11 eq | 1.03E-01 | 5.25E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.46E-05 | 0.00E+00 | 1.09E-01 | 1.09E-01 |
| Smog Potential | kg O3 eq | 2.47E+05 | 7.71E+05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.50E+05 | 0.00E+00 | 1.17E+06 | 1.17E+06 |
| Total Primary Energy | MJ | 5.33E+07 | 3.01E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.98E+06 | 0.00E+00 | 8.84E+07 | 8.84E+07 |
| Non-Renewable Energy | MJ | 5.32E+07 | 3.01E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.98E+06 | 0.00E+00 | 8.83E+07 | 8.83E+07 |
| Fossil Fuel Consumption | MJ | 4.20E+07 | 2.95E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.97E+06 | 0.00E+00 | 7.65E+07 | 7.65E+07 |

42

## Proposed Building Option 1 Impacts

| | | PRODUCT (A1 to A3) | CONSTRUCTION PROCESS (A4 & A5) | USE (B2, B4 & B6) | | | END OF LIFE (C1 to C4) | BEYOND BUILDING LIFE (D) | TOTAL EFFECTS | |
|---|---|---|---|---|---|---|---|---|---|---|
| Summary Measure | Unit | Total | Total | Replacement Total | Operational Energy Use Total | Total | Total | Total | A to C | A to D |
| Global Warming Potential | kg CO2 eq | 3.94E+06 | 2.21E+06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.60E+05 | 0.00E+00 | 6.51E+06 | 6.51E+06 |
| Acidification Potential | kg SO2 eq | 1.99E+04 | 2.28E+04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.25E+03 | 0.00E+00 | 4.70E+04 | 4.70E+04 |
| HH Particulate | kg PM2.5 eq | 5.20E+03 | 1.35E+03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.51E+02 | 0.00E+00 | 6.70E+03 | 6.70E+03 |
| Eutrophication Potential | kg N eq | 1.64E+03 | 1.55E+03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.85E+02 | 0.00E+00 | 3.48E+03 | 3.48E+03 |
| Ozone Depletion Potential | kg CFC-11 eq | 1.05E-01 | 5.31E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.47E-05 | 0.00E+00 | 1.10E-01 | 1.10E-01 |
| Smog Potential | kg O3 eq | 2.27E+05 | 7.72E+05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.50E+05 | 0.00E+00 | 1.15E+06 | 1.15E+06 |
| Total Primary Energy | MJ | 4.30E+07 | 2.97E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 5.00E+06 | 0.00E+00 | 7.77E+07 | 7.77E+07 |
| Non-Renewable Energy | MJ | 4.27E+07 | 2.97E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 5.00E+06 | 0.00E+00 | 7.74E+07 | 7.74E+07 |
| Fossil Fuel Consumption | MJ | 3.11E+07 | 2.91E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.99E+06 | 0.00E+00 | 6.52E+07 | 6.52E+07 |

43

## Proposed Building Option 2 Impacts

| | | PRODUCT (A1 to A3) | CONSTRUCTION PROCESS (A4 & A5) | USE (B2, B4 & B6) | | | END OF LIFE (C1 to C4) | BEYOND BUILDING LIFE (D) | TOTAL EFFECTS | |
|---|---|---|---|---|---|---|---|---|---|---|
| Summary Measure | Unit | Total | Total | Replacement Total | Operational Energy Use Total | Total | Total | Total | A to C | A to D |
| Global Warming Potential | kg CO2 eq | 3.92E+06 | 2.16E+06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.51E+05 | 0.00E+00 | 6.43E+06 | 6.43E+06 |
| Acidification Potential | kg SO2 eq | 1.76E+04 | 2.21E+04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.14E+03 | 0.00E+00 | 4.39E+04 | 4.39E+04 |
| HH Particulate | kg PM2.5 eq | 4.72E+03 | 1.30E+03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.47E+02 | 0.00E+00 | 6.17E+03 | 6.17E+03 |
| Eutrophication Potential | kg N eq | 1.59E+03 | 1.51E+03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.78E+02 | 0.00E+00 | 3.38E+03 | 3.38E+03 |
| Ozone Depletion Potential | kg CFC-11 eq | 8.28E-02 | 4.22E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.43E-05 | 0.00E+00 | 8.71E-02 | 8.71E-02 |
| Smog Potential | kg O3 eq | 1.94E+05 | 7.52E+05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.46E+05 | 0.00E+00 | 1.09E+06 | 1.09E+06 |
| Total Primary Energy | MJ | 3.85E+07 | 2.88E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.88E+06 | 0.00E+00 | 7.22E+07 | 7.22E+07 |
| Non-Renewable Energy | MJ | 3.83E+07 | 2.88E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.88E+06 | 0.00E+00 | 7.20E+07 | 7.20E+07 |
| Fossil Fuel Consumption | MJ | 2.92E+07 | 2.83E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.87E+06 | 0.00E+00 | 6.23E+07 | 6.23E+07 |

44

## Final Results

| Building | GWP (kg/yd$^3$) | GWP Reduction |
|---|---|---|
| Reference Mixes | 6.14 x $10^6$ | 0 |
| Proposed with Slag Mixes | 3.94 x $10^6$ | -36% |
| Proposed with Fly Ash and Slag | 3.92 x $10^6$ | -36% |

45

## Proposed Specification Language

**Option 1**

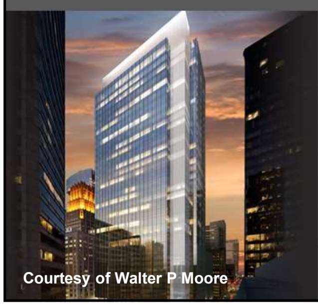
Supply concrete mixtures such that the total Global Warming Potential (GWP) of all concrete on the project is less than or equal to 4,298,000 kg of $CO_2$ equivalents as calculated using the Athena Impact Estimator for Buildings Software available at www.athenasmi.org.

**Option 2**

Supply concrete mixtures such that the total Global Warming Potential (GWP) of all concrete on the project is 30% or more below the GWP of a reference building using Benchmark mixes as established by NRMCA and available for download at www.nrmca.org. Submit a summary report of all the concrete mixtures, their quantities and their GWP to demonstrate that the total GWP of the building is 30% or more below the GWP of the reference building. Contractor may use the Athena Impact Estimator for Buildings software available at www.athenasmi.org or other similar software with the capability of calculating GWP of different mix designs.

46

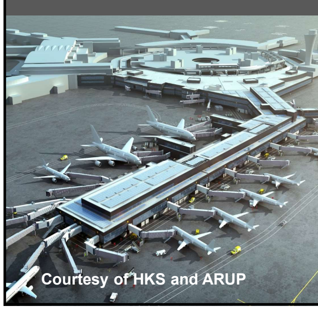
## Case Study: Capitol Tower , Houston




- 35-stories
- 750,000 $ft^2$
- Concrete Frame
- LEED EPD and LCA Credit
- High Volume SCM Mixes
- 19% Reduction in $CO_2$

47

## Case Study: San Francisco Airport Expansion




- $2.4 million expansion
- Concrete and Steel Frame
- LEED EPD and LCA Credit
- High Volume SCM Mixes
- 20% Reduction in $CO_2$

48

## Conclusion

**What we have learned:**

- We have looked at the difference between performance-based specification and prescriptive specifications
- Discover how performance-based specifications can improve performance and lower environmental impacts of concrete structures.
- Learn how to implement performance-based specifications in projects.
- Demonstrate the importance of balancing structural and architectural performance of concrete with green building strategies.

49

## Thank you

Donn C. Thompson, AIA, LEED AP BD+C
National Ready Mixed Concrete Association
McHenry, IL
dthompson@nrmca.org 224.627.3933


**Free Collaboration Design/Construction Team:**

- Structural system recommendations
- First and operating cost comparisons
- Specification review

www.buildwithstrength.com/design-center

BUILD WITH STRENGTH

NRMCA

50

## How Do I Write a Sustainable Concrete Specification?

Donn C. Thompson AIA, LEED AP BD+C
National Ready Mixed Concrete Association

NRMCA

SUSTAINABLE STRUCTURES WEBINAR SERIES

51