CIVIL AND ENVIRONMENTAL ENGINEERING

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Earth block construction:
a sustainable housing solution for the wildland-urban interface (WUI)

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Outline

- Introduction
- Traditional Earthen Structures
- Earthen Construction: Advantages and Challenges
- Compressed and Stabilized Earth Block (CSEB) Construction
- Feasibility of Earthen Houses
- Wildfire Performance Assessment of CSEBs

Introduction

- Earthen structures built using mainly soil
- Very ancient techniques
- Several economic and sustainability advantages over more modern techniques
- A few significant challenges, particularly for non-engineered earthen structures
- Modern earthen construction techniques developed to address these issues, e.g., earth block construction
- Current research at UC Davis extending the use of earth block construction for fireproof buildings in the WUI

Traditional Earthen Structures (1)

- Cob
  - Sand, clay, water, some kind of fibrous or organic material (straw)
  - Soil mix is layered to build earth structures

- Rammed earth
  - Mixture of sand, clay, water, fiber, and gravel
  - Soil mix is compacted to build earth structures

- Adobe/earth blocks
  - Mixture of sand clay, water, and fibers is used to fabricate blocks
  - Earth structures are built with these blocks

Traditional Earthen Structures (2)

Great Mosque of Djenné in Mali
(300 BCE)

Portions of the Great Wall built with rammed earth
(300 BCE - 1700 CE)

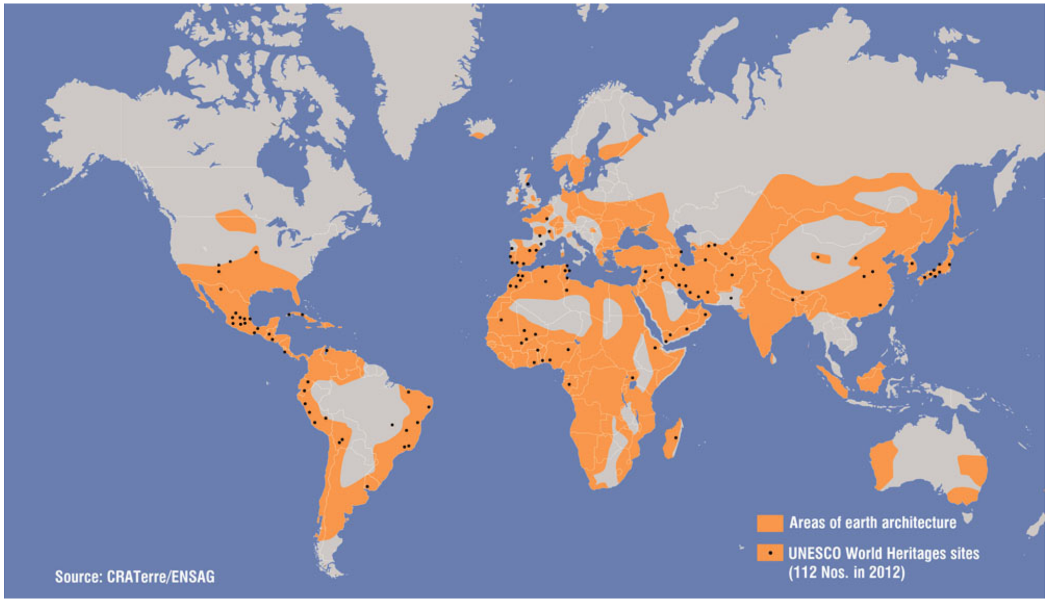
Pueblo de Taos in USA
(1100 CE – 1500 CE)

City of Potosí in Bolivia
(1600 CE – 2000 CE)

(Gandreau and Delboy 2012)

Earthen Construction: Advantages (1)

- Affordable and locally appropriate
  - Soil is a widely available and inexpensive material
  - This construction type is widely used around the world

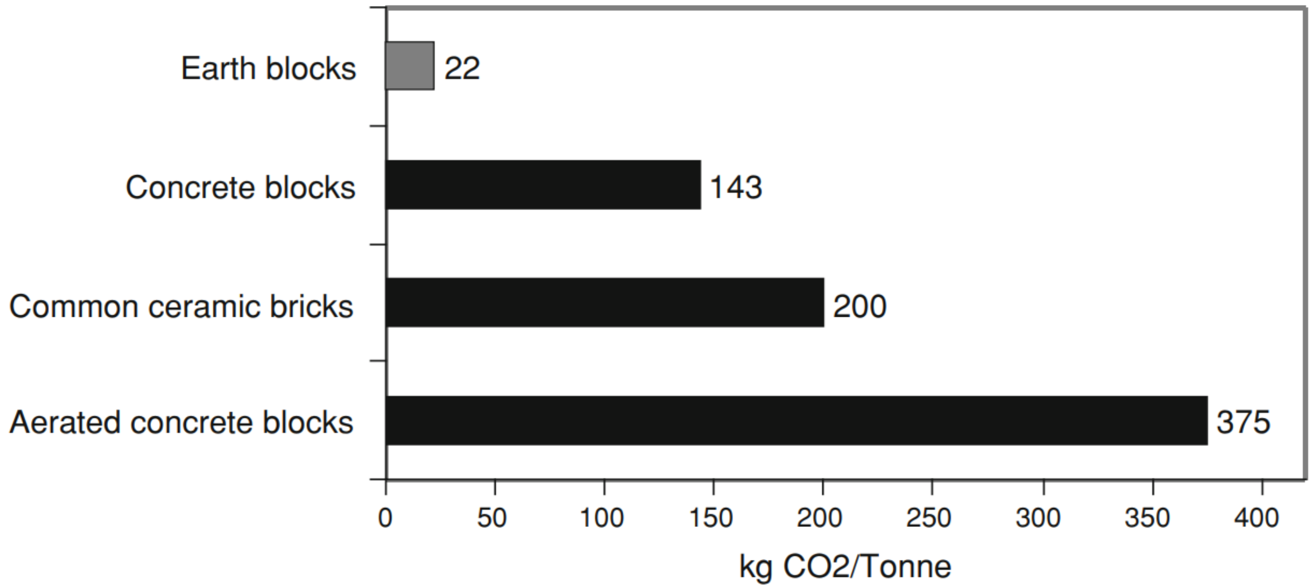


Earth construction areas of the world
(Auroville Earth Institute)

- Indoor air quality and humidity efficient
  - Earthen construction can keep the relative humidity of indoor air between 40% and 60%, which is most suitable for human health.

Earthen Construction: Advantages (2)

- Eco-efficient and sustainable
  - The embodied energy of earth buildings is significantly smaller than that of other conventional construction techniques

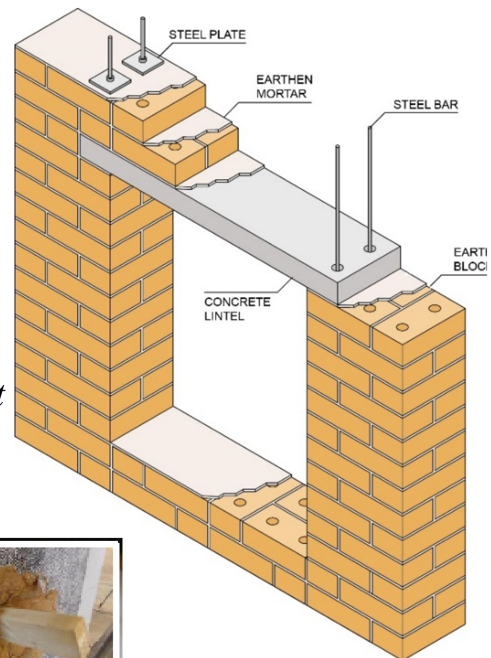


Embodied carbon in different masonry materials (Morton et al. 2005)

- Very good isolation properties
  - High R-values, > 30% in HVAC energy savings

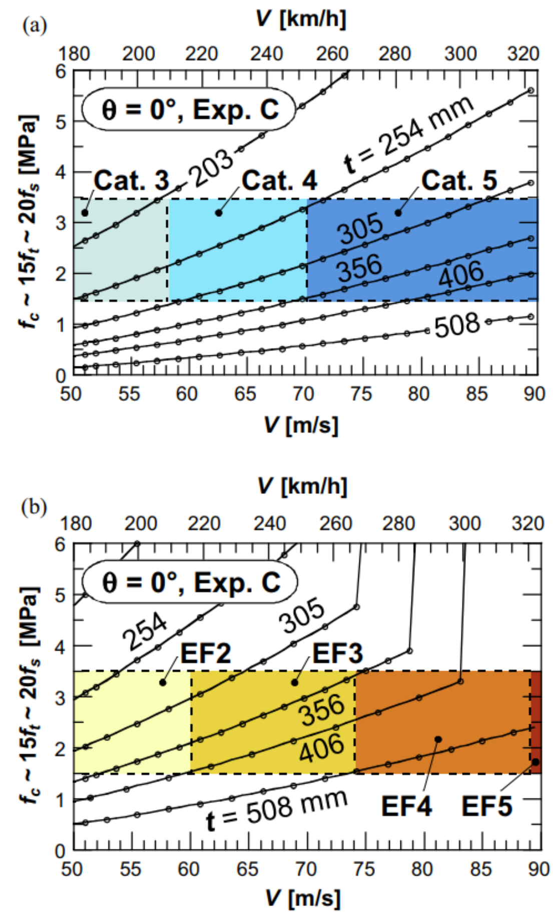
Earthen Construction: Advantages (3)

- Good hazard resistance
  - Hurricane resistance
  - Tornado resistance
  - Seismic resistance
  - Non-combustible



Structural detail for seismic-resistant reinforced earth block construction

Windborne debris impact resistance of earth block walls (Cuéllar-Azcárate MC 2016)



Masonry strength demand curves: (a) hurricane effects; and (b) tornado effects (Matta et al. 2015)

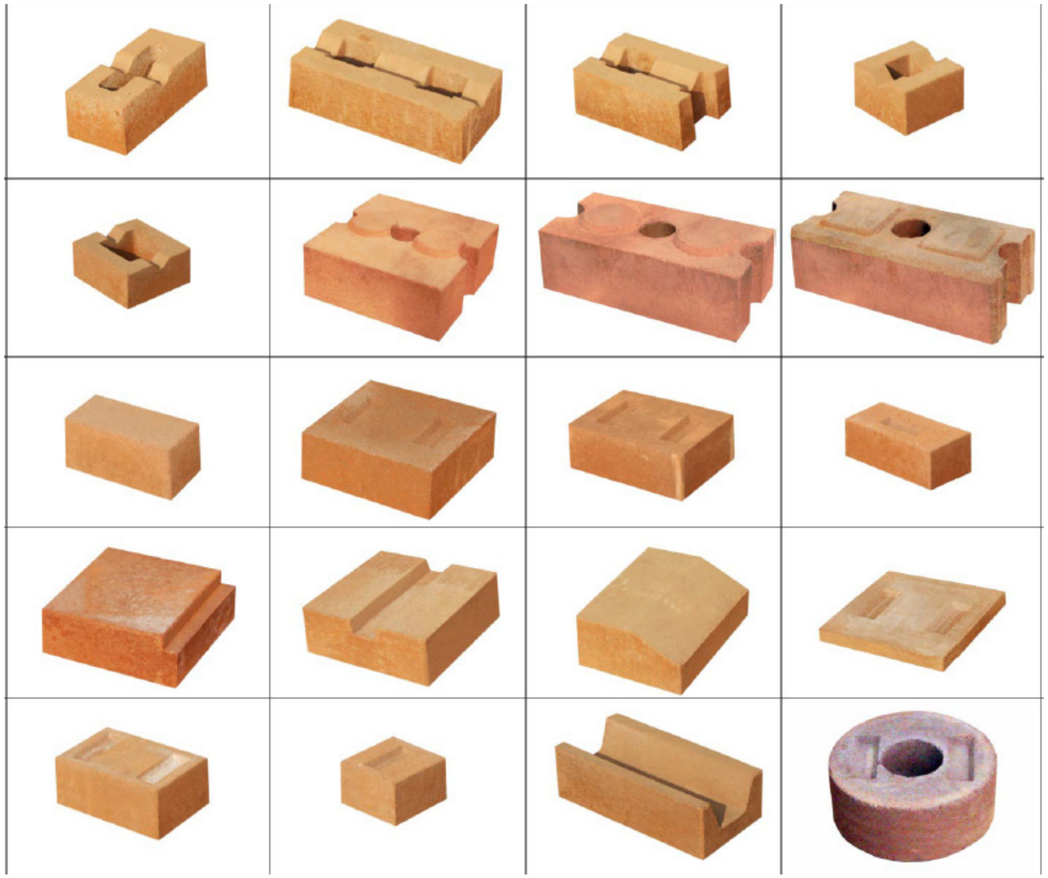
Earthen Construction: Challenges

- ➢ High variability of soil properties
- ➢ Poor durability against wet climates
- ➢ Brittleness
- ➢ Widespread perception as a substandard choice
- ➢ Typically not thought in structural engineering curricula

The Ricola Herb Centre in Laufen (Basel), Switzerland

Childcare facility in Glendale, California

Compressed and Stabilized Earth Block (CSEB) Construction



- Masonry built using earth block fabricated by mechanically compressing a chemically stabilized soil mixture

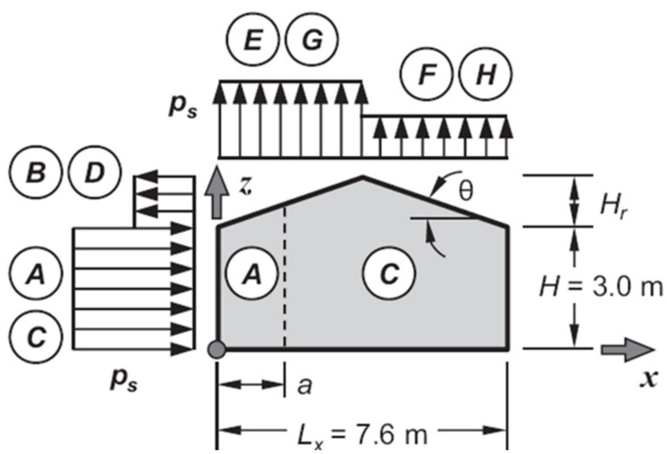
Feasibility of Earthen Houses

- Focus on US Gulf Coast region (wet and humid climate)
- Motivation: need for affordable hurricane-resistant housing
  - 386,000 low-income households in Louisiana need affordable housing (U.S. Department of Housing and Urban Development in 2010)
- Challenges: poor soil quality, hot and wet climate, high wind loads, and cost
- Need for culturally-appropriate solutions
- Investigation performed for:
  - Structural feasibility
  - Architectural feasibility
  - Economic feasibility

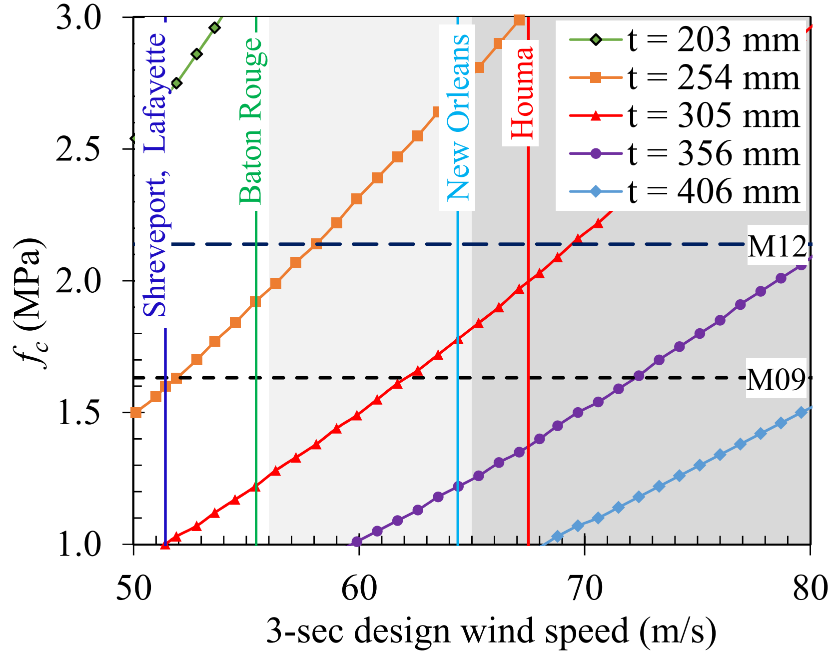
(Kumar et al. 2018)

Hurricane Wind Resistance Study

- Strength demand curves developed by Matta et al. (2015)
- Characteristic masonry strength as per Eurocode 6 (CEDN 2005)
  - M09 - CSEB with 09% cement and respective mortar
  - M12 - CSEB with 12% cement and respective mortar



Schematic representation of wind pressures on MWFRS (Matta et al. 2015)



CSEB masonry strength demand curves for hurricane

Durability Study of CSEB Wall

Masonry wall after construction

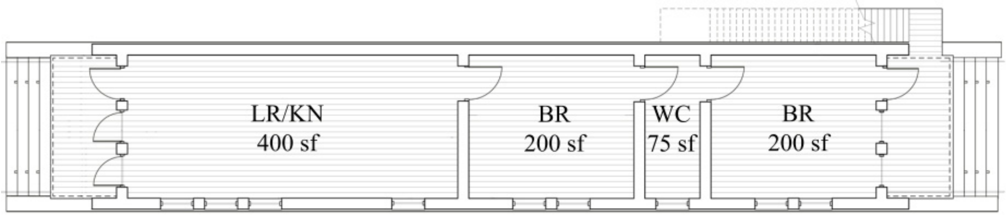
Masonry wall after application of soil-cement mortar

Mechanical properties of CBEBs before construction and after demolition of the wall

Tested specimens	MOR		f_{bd}		MOE	
	Average (MPa)	COV (%)	Average (MPa)	COV (%)	Average (MPa)	COV (%)
CSEB (initial)	0.57	11.28	1.38	6.40	31.22	16.98
CSEB (protected)	0.64	22.68	1.79	5.55	55.61	20.21
CSEB (unprotected)	0.37	21.82	1.50	13.80	44.78	26.82

MOR = modulus of rupture; f_{bd} = dry compressive strength; **MOE** = modulus of elasticity

Architectural & Economic Feasibility



Floor plan

Front elevation

Front elevation

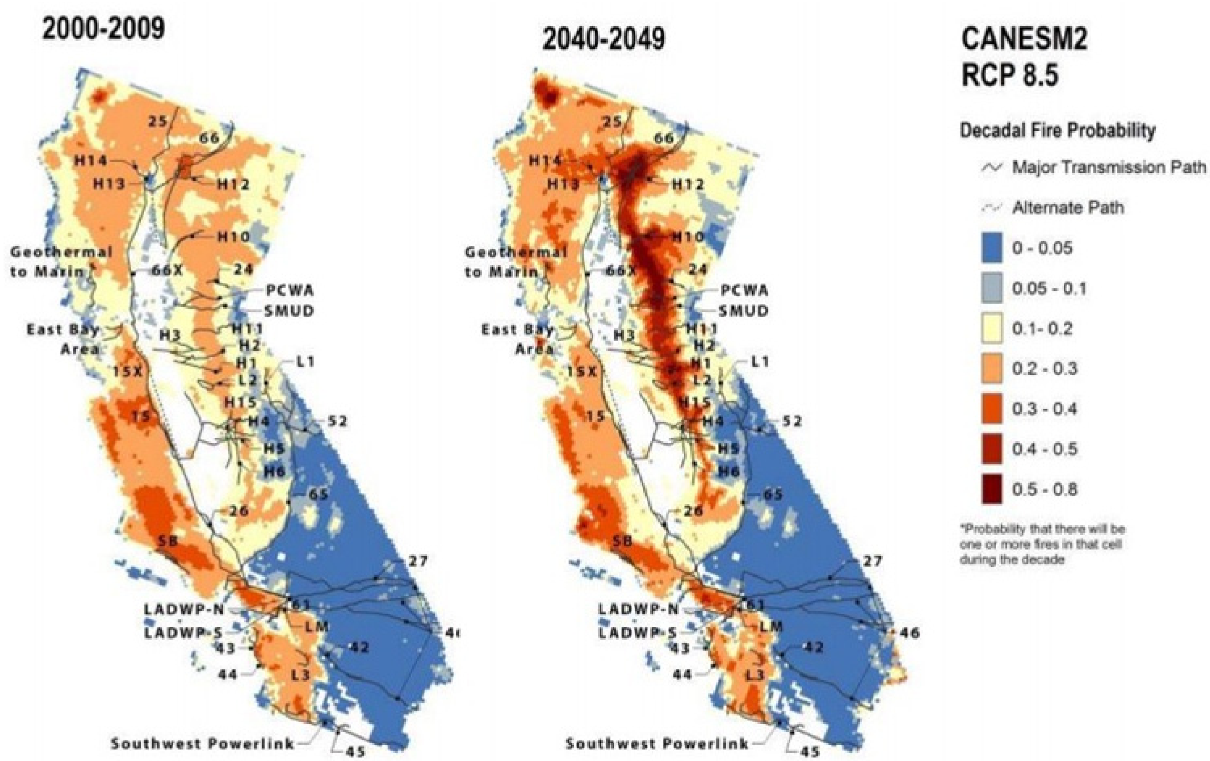
Cost comparison of different wall systems for reference shotgun prototypes house (1000 Square ft.)

Items	Mortarless ICSEB	Mortared CSEB	Light-frame wood	Bricks	Concrete blocks
Material ($)	7,186	6,676	15,638	19,533	12,844
Labor ($)	20,593	34,674	13,068	27,625	20,255
Overhead ($)	11,112	16,540	12,264	19,840	13,882
Total wall cost ($)	**38,891**	**57,890**	**40,970**	**66,997**	**46,981**
Other assemblies ($)	65,110	65,110	65,110	65,110	65,110
Total cost of house ($)	**104,001**	**123,000**	**106,080**	**132,107**	**112,091**
Wall cost ratio (wcr)	1.00	1.49	1.05	1.72	1.21
House cost ratio (hcr)	**1.00**	**1.18**	**1.02**	**1.27**	**1.08**

- RS Means (2014, 2015) is used for the cost estimation

Wildfire Performance Assessment of CSEBs (1)

- Rising global temperatures are increasing the severity of wildfires across the western United States (Westerling 2018: CEC Report No. CCCA4-CEC-2018-014)



Wildfire simulations for California's 4th Climate Change Assessment projecting changes in extreme wildfire events under a warming climate

Wildfire Performance Assessment of CSEBs (2)

Number of residences at wildfire risk by state

State	Low	Moderate	High	Extreme
Arizona	2,143,760	9,590	36,811	34,491
California	8,896,509	138,821	405,715	240,580
Colorado	1,674,723	33,461	91,026	113,002
Idaho	531,676	10,752	31,195	37,624
Montana	304,960	9,820	24,147	28,955
New Mexico	553,918	9,287	42,843	38,101
Nevada	939,019	1,104	7,998	6,989
Oklahoma	1,310,426	284	383	172
Oregon	1,191,803	21,642	57,083	74,703
Texas	7,836,840	73,957	195,366	174,038
Utah	779,926	8,969	13,863	3,563
Washington	2,359,166	7,690	15,510	18,508
Wyoming	193,790	1,461	2,683	4,928

Wildfire Performance Assessment of CSEBs (3)

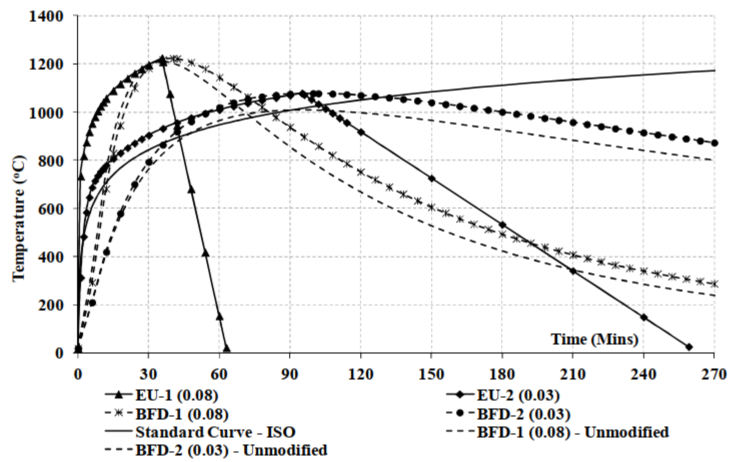
Reconstruction cost value of residence at risk by state (in $billions)

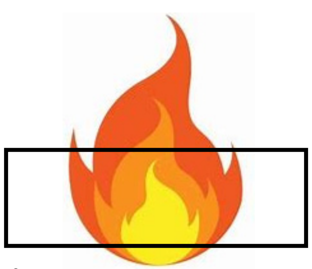
State	Low	Moderate	High	Extreme
Arizona	$448.74	$2.04	$7.95	$7.73
California	$3,381.07	$61.92	$189.00	$92.62
Colorado	$401.65	$9.55	$27.05	$33.66
Idaho	$122.70	$2.65	$7.52	$9.05
Montana	$65.55	$2.38	$5.94	$6.96
New Mexico	$116.66	$2.27	$10.66	$9.23
Nevada	$247.89	$0.39	$3.21	$2.92
Oklahoma	$249.75	$0.05	$0.06	$0.03
Oregon	$297.22	$5.46	$14.33	$18.64
Texas	$1,717.30	$16.86	$42.97	$32.30
Utah	$187.62	$3.11	$5.02	$1.19
Washington	$608.26	$1.92	$4.00	$4.61
Wyoming	$43.60	$0.36	$0.67	$1.27

Wildfire Performance Assessment of CSEBs (4)

- Research Plan
  - Characterize fire-induced changes in mechanical properties of CSEBs and CSEB masonry at different temperatures and temperature gradients
  - Investigate the integration of other fire hardening systems (roof system and cover, vents, defensible space, etc.)
  - Assess smoke toxicity of CSEBs houses compared to light-framed wooden houses

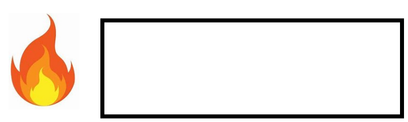
Design code-based fire time-temperature curves





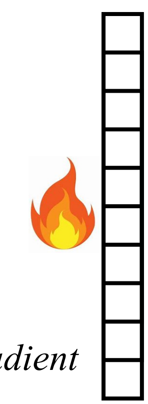
Uniform temperature increase

CSEBs



Temperature gradient

CSEB walls



Temperature gradient

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Thank you
Questions?

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