Economic Evaluation of Building Insulation Measures

Final Deliverable (Revised)

12/31/2021

Insulation Institute
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Agenda

- Grid Interactive Efficient Building
- Approach
  - Simulation Data
    - Modeling inputs and Insulation Levels
    - GEB considered
  - Cost-effectiveness evaluation
- Results and Key Takeaways – Residential and Commercial
  - Daily usage and demand curve reduction
  - Cost-effectiveness/Economic evaluation
- Conclusions
- Appendices (Insulation levels and upgrades)

Approach

Grid-Interactive Efficient Building

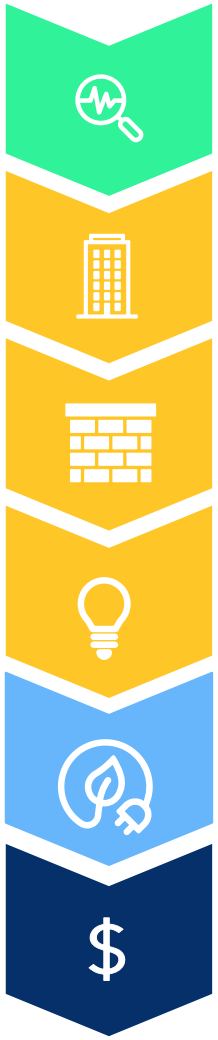
- Grid-interactive efficient buildings (GEBs) are energy efficient buildings with smart technologies to optimize energy use for grid services, occupant preferences, climate mitigation, and cost reductions in a continuous and integrated way.

Examples of GEB measures providing value to the grid –

1. A Building having an efficient controls-based HVAC system to reduce heating/cooling energy needs as required.
2. Incorporating lighting controls that dims lighting system by a preset amount in response to grid signals while maintaining occupant visual comfort levels.
3. Connected water heaters that pre-heat water during off-peak periods in response to grid signals.
4. Batteries and inverters which autonomously modulate power draw to help maintain grid frequency or control system voltage.
5. Rooftop solar PV exports electricity to the grid.

Approach

01	Data gathering	• Existing models developed by the US Department of Energy (DOE) • Insulation upgrade costs
02	Baseline	• Simulation of the default DOE models as baseline
03	Insulation upgrade	• Energy Simulation - Average Insulation upgrades • Energy Simulation - High Insulation upgrades
04	Insulation + GEB upgrade	• Energy Simulation - Insulation upgrade + GEB Technology
05	Energy savings evaluation	• Daily curve and energy usage difference charts
06	Economic impact evaluation	• Cost-effectiveness - levelized cost of energy



Simulation Data – Modeling Inputs

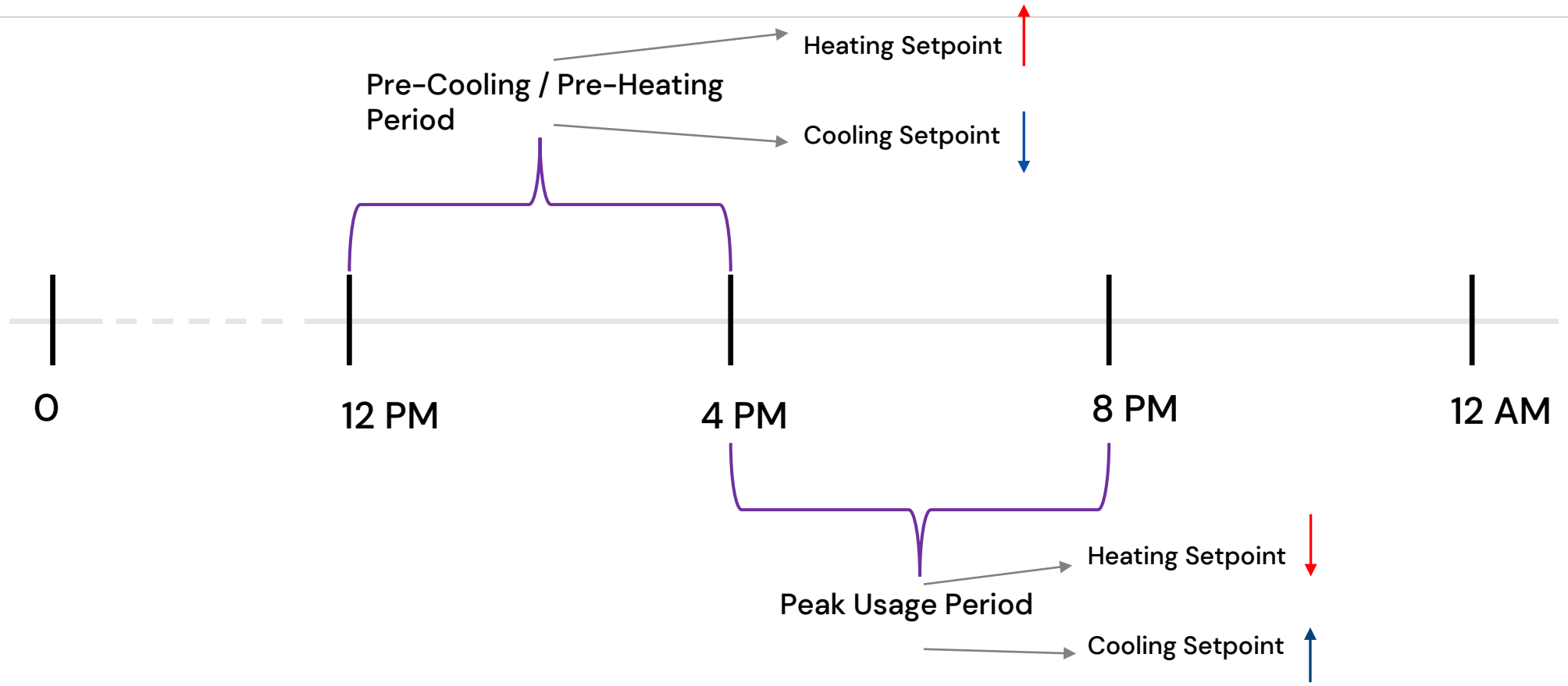
- Climate Zones - ASHRAE Climate Zone 3A and 5A
  - Climate zone 3A → warm – humid → represented by Atlanta, GA
  - Climate zone 5A → cool - humid → represented by Detroit, MI
- TMY3 Weather Patterns (Reference: *GEB Roadmap*)
- Building Models
  - Residential – NREL ResStock based sample
  - Commercial – DOE prototype models
- Cost and Retail Price Data
  - Utility prices – 2021 US electric rate (*Source: Energy Information Administration*)
  - Insulation costs – RS Means and Home Depot
- Real discount rate for net present value calculations – 2.00 % (Reference: *GEB Roadmap*)
- Annual Electricity Rate Escalation – 1.15% (*Source: Energy Information Administration*)
- Insulation Service Life – 20 Years (*Source: Database for Energy-Efficient Resources, Version 2008*)
- GEB - demand flexibility upgrades
  - Temperature adjustment driven by peak hours

Simulation Data – Insulation Levels

- Wall and roof insulations were upgraded from their respective current i.e., baseline levels, to create two scenarios for analysis
- The two upgrade levels are terms as ‘upgrade 1’ and ‘upgrade 2’
- Baselines and upgrade levels may vary across the two climate zones; while the baselines come from the prototype models, the upgrade levels are subject to additional constraints such as available cost data
- Residential
  - Wall baseline ranges between R7 and R11; resultant upgrades for the two scenarios range from R13 through R20.
  - Roof baseline ranges between R20 to R38; and the upgrades span the range of R30 through R60.
- Commercial
  - Wall baseline ranges between R7 and R20; resultant upgrades for the two scenarios range from R11 through R20.
  - Roof baseline ranges between R24 to R30; and the upgrades span the range of R38 through R49.

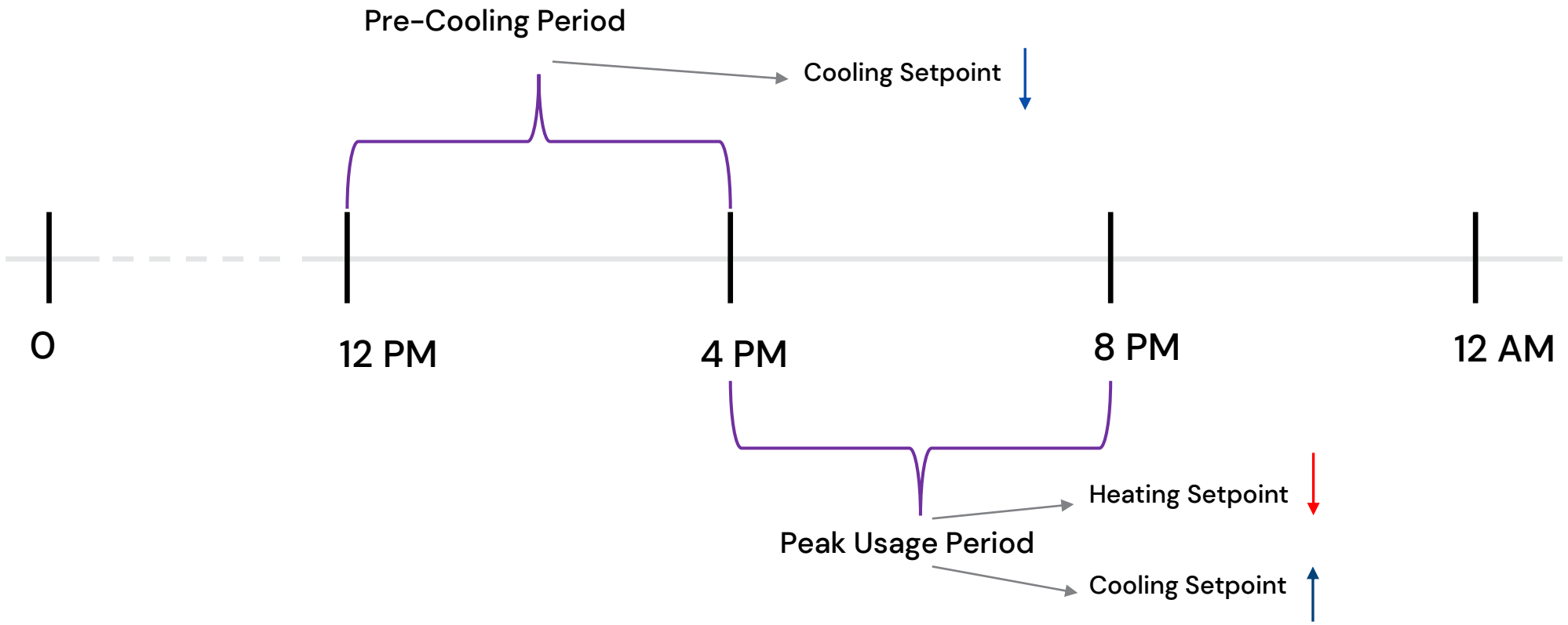
Building specific assumptions are detailed in the Appendix

Residential GEB - Peak Hours and temperature adjustments



- Residential peak hours occur between 4 – 8 PM on all days of the week including weekends
- The thermostat setpoints in the peak hours are adjusted by 3F (reduced in winter and increased in summer) depending on prevalent thermostat setpoint
- Pre-cooling and pre-heating of homes precedes peak hours and lasts for 4 hours. The temperature is adjusted by 3F (increased in winter and reduced in summer) during pre-cooling and pre-heating periods

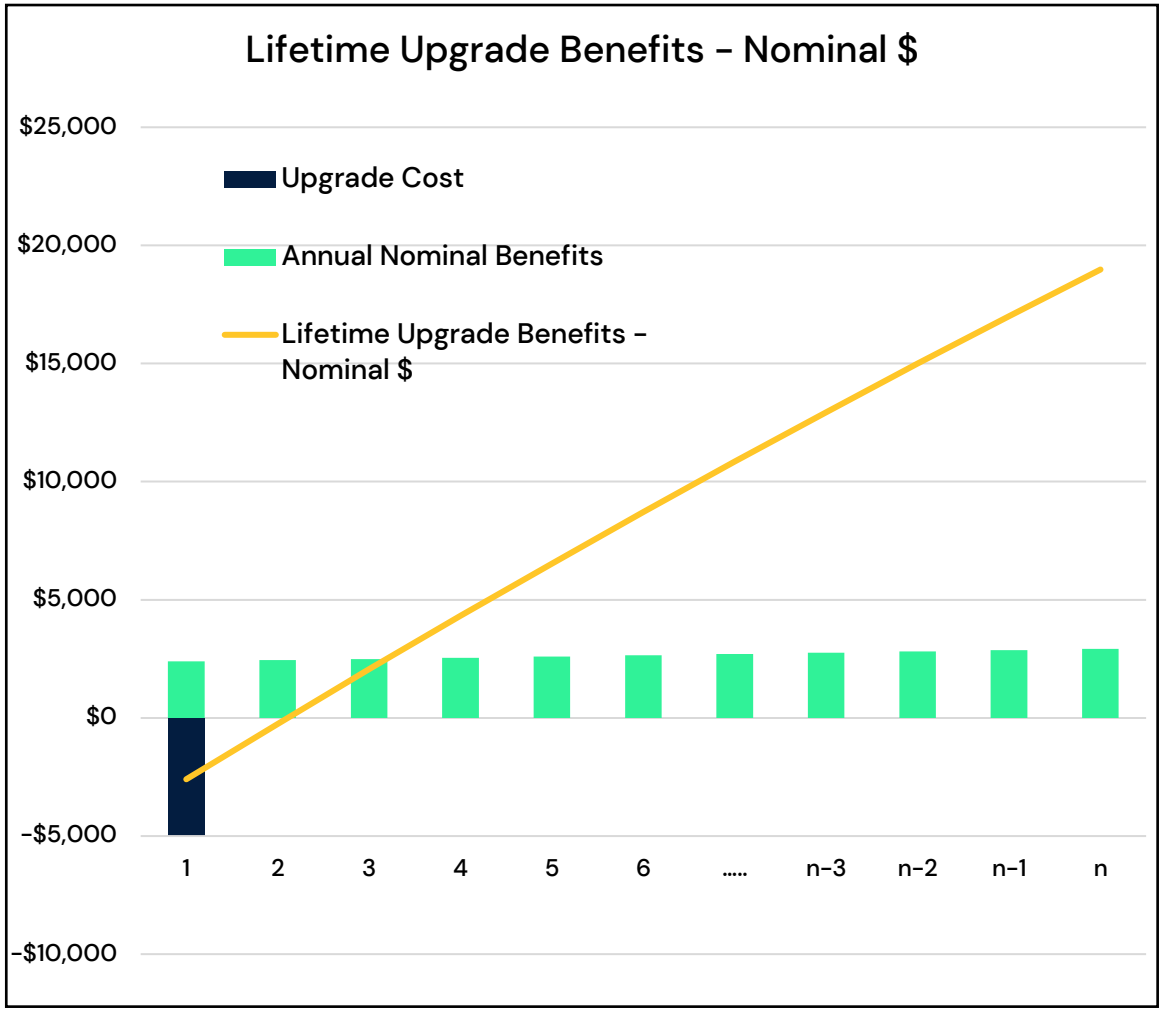
Commercial GEB - Peak Hours and temperature adjustments



- Commercial sector peak hours occur on weekdays between 4 – 8 PM
- The thermostat setpoints in the peak hours increase from 75F to 80F during summer and decrease from 70F to 68F during winter
- Commercial spaces are pre-cooled by a reduction from 75F to 73F but not pre-heated since risk of discomfort at 68F is low

Cost-Effectiveness Evaluation

- Cost-Effectiveness of insulation upgrades is evaluated
  - from a customer perspective, using levelized cost of energy* takes into account, annual bill savings and initial upgrade costs over the useful life of 20 years*
- Annual bill savings are calculated using average residential and commercial electricity rates in the United States sourced from Energy Information Administration data.
- Utility rates are escalated annually over the useful life of insulation upgrades.
- Net savings from insulation upgrades are calculated through net present value calculation using '*GEB Roadmap*' determined discount rate.
- Cost Effectiveness is determined through levelized cost of energy (LCOE) metric; a positive LCOE refers to cost-effective investment.



*Source: Database for Energy-Efficient Resources, Version 2008

Results and Key Takeaways

Results – Daily Usage Reduction

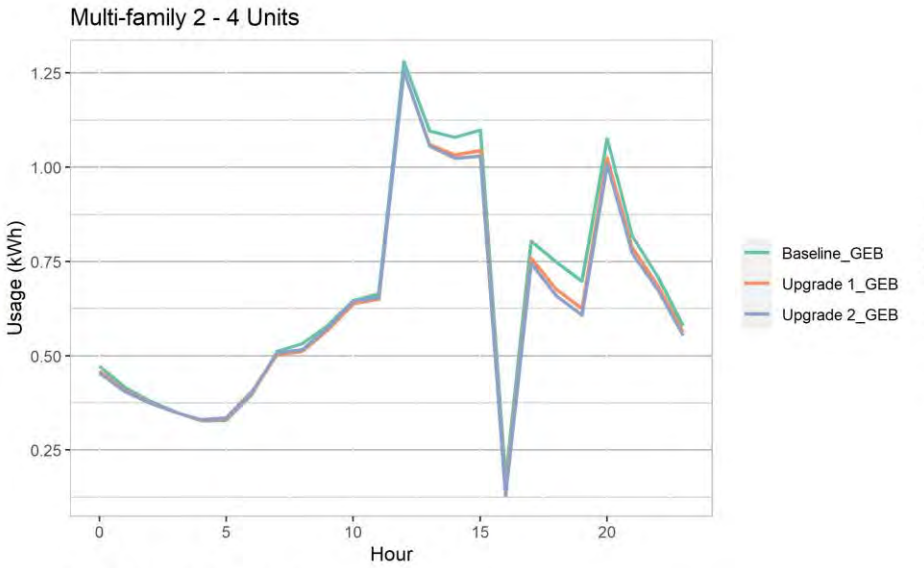
- The charts in the following slides show the effect of insulation - when combined with the GEB i.e., indoor temperature setpoint adjustment - on the daily energy/demand usage during months of summer and winter season
- The daily usage trend can be broadly classified into four periods due to the GEB –
  - pre-cooling/pre-heating period with higher-than-normal usage, followed by
  - peak period of reduced usage, followed by
  - a snapback where the setpoint returns to the normal level, and
  - GEB impact-free period on either end of the 24-hour
- The interaction of thermostat cooling & heating setpoint adjustments, ambient temperature in the climate zone, housing insulation levels and other characteristics govern the cooling & heating loads and resultant energy consumption in a typical home

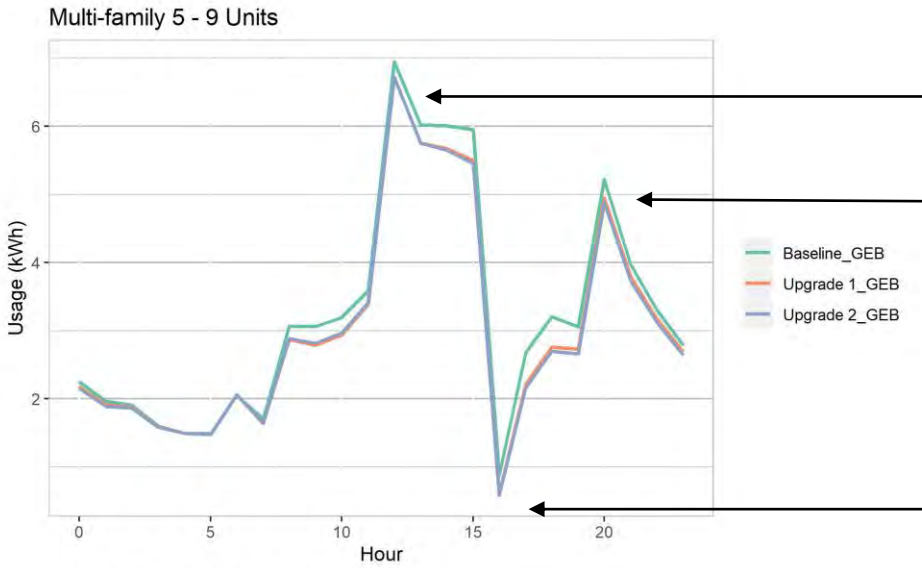
Residential

Residential Key Takeaways

- Higher insulation levels labelled as ‘upgrade 1’ and ‘upgrade 2’ show reduced peak period usage across all building types. For upgrade 1,
  - The highest reduction in cooling energy is seen in single family detached at ~12%, while the lowest effect is seen in single family attached configuration unit at ~3%
  - Heating energy reductions vary between ~5% in Multifamily buildings with 2 -4 Units and 12% in Single Family Attached
- Multi-family buildings with 5–9 units in climate zone 3A witness a significant savings in cooling energy usage but show nil savings in the peak period in winter season for insulation upgrades.
  - Characteristic to climate zone 3A, high temperatures in summer coincide with the peak period when better insulation prevails in retaining the cooling comfort level. However, a reverse trend is seen when assessing the heating energy usage.
  - The behavior is attributed to low heating setpoints in the prevalent building and the ambient weather in climate zone 3A. Low magnitudes of temperature differentials between heating setpoints and ambient weather during winter peak usage period display a muted response in heating energy savings to increases insulation levels.

Summer Daily Usage – Climate Zone 3A

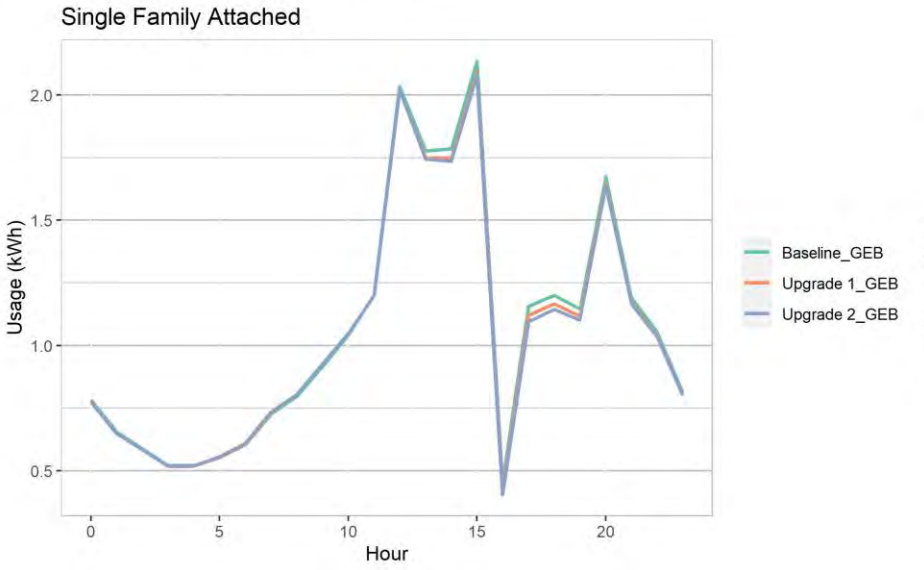


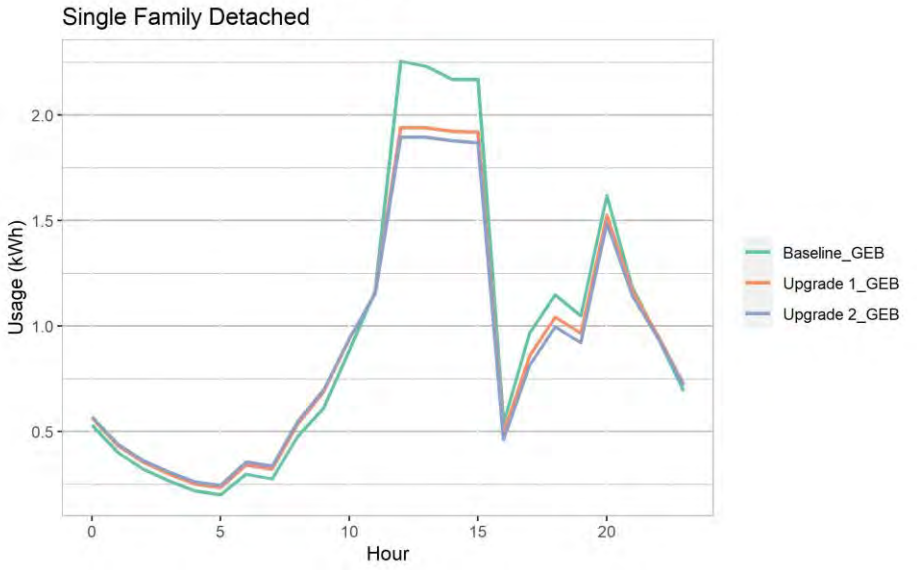


Pre-Cooling

Snapback Period

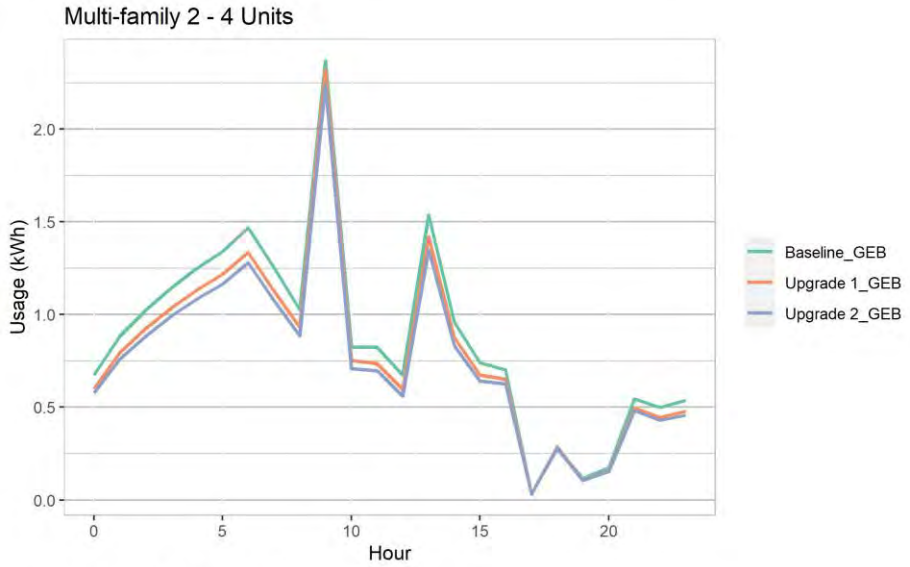
Peak Period

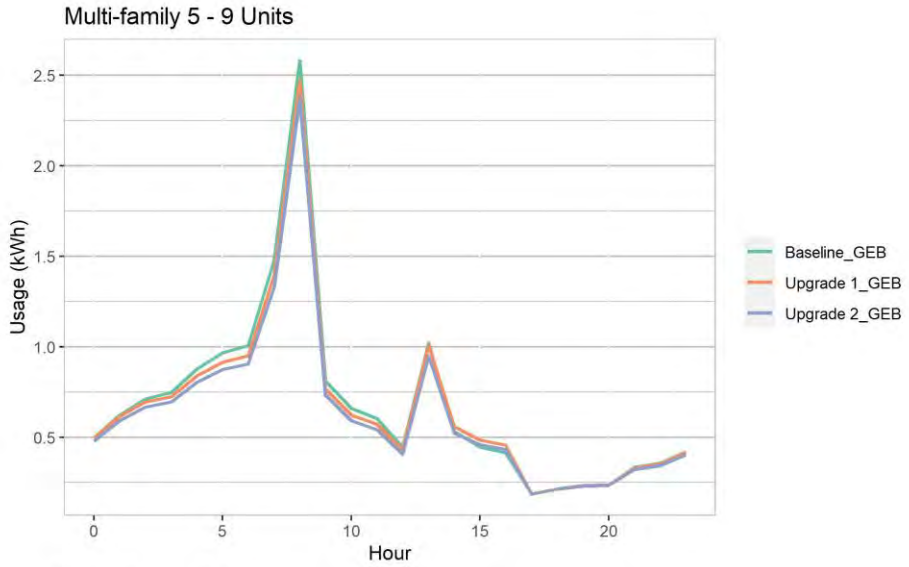


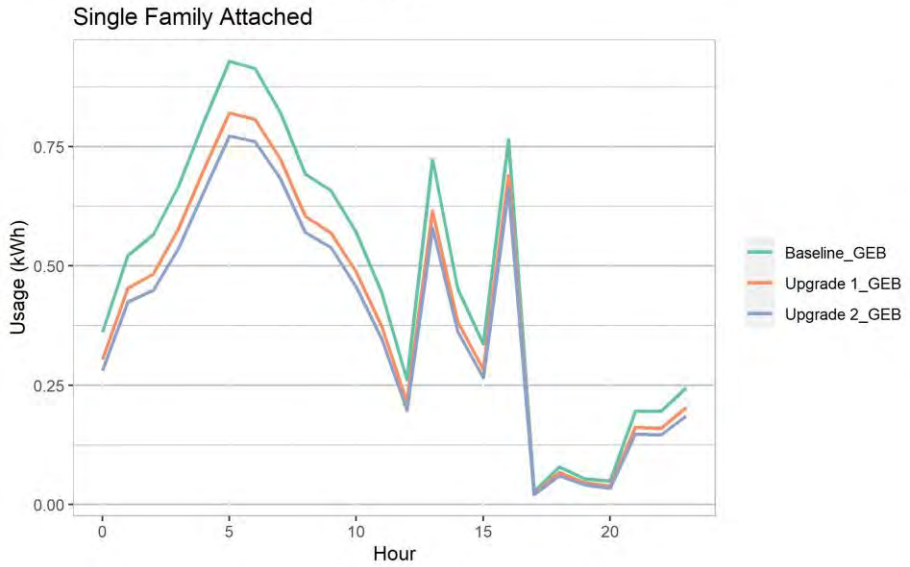


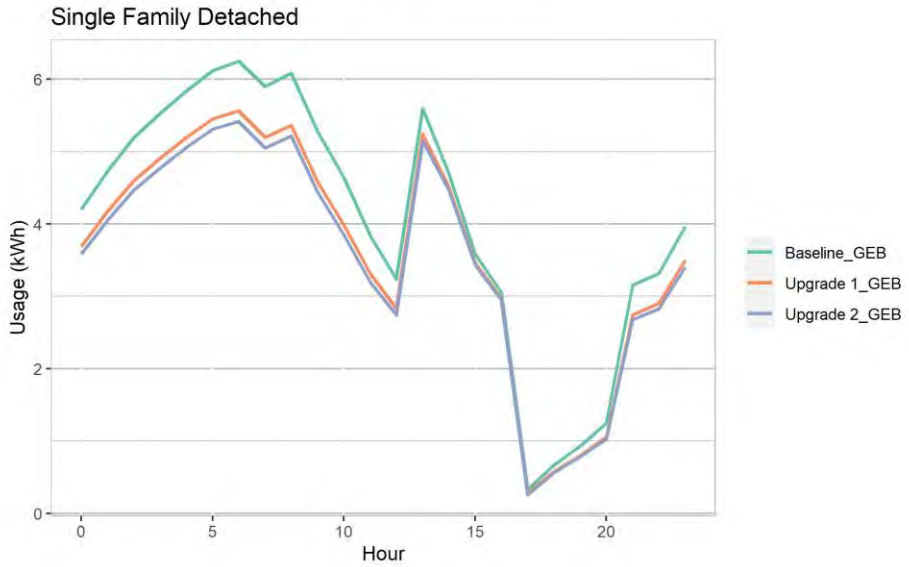
- Baseline_GEB = Baseline prototype with GEB technology enabled
- Upgrade 1_GEB = First level insulation upgrades with GEB technology enabled
- Upgrade 2_GEB = Second level insulation upgrades with GEB technology enabled

Winter Daily Usage – Climate Zone 3A

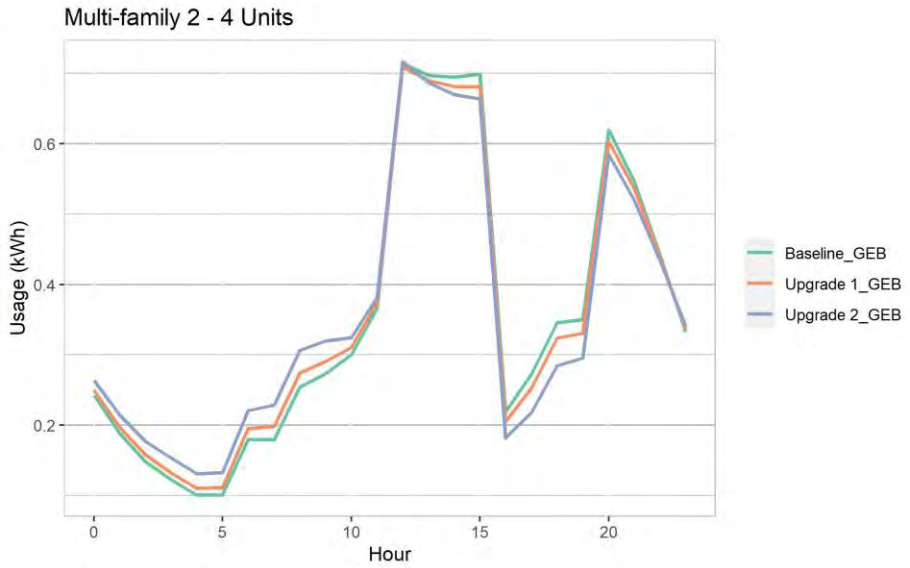


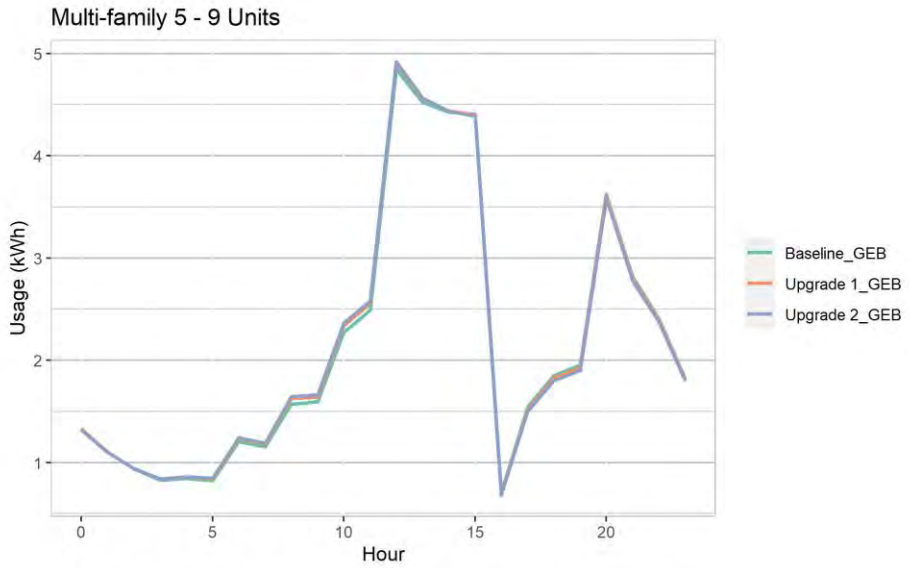


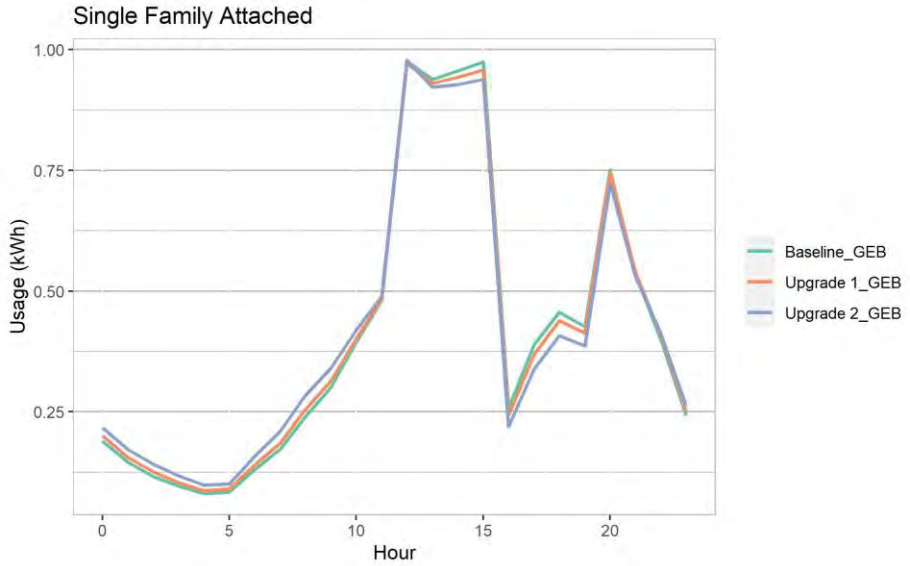


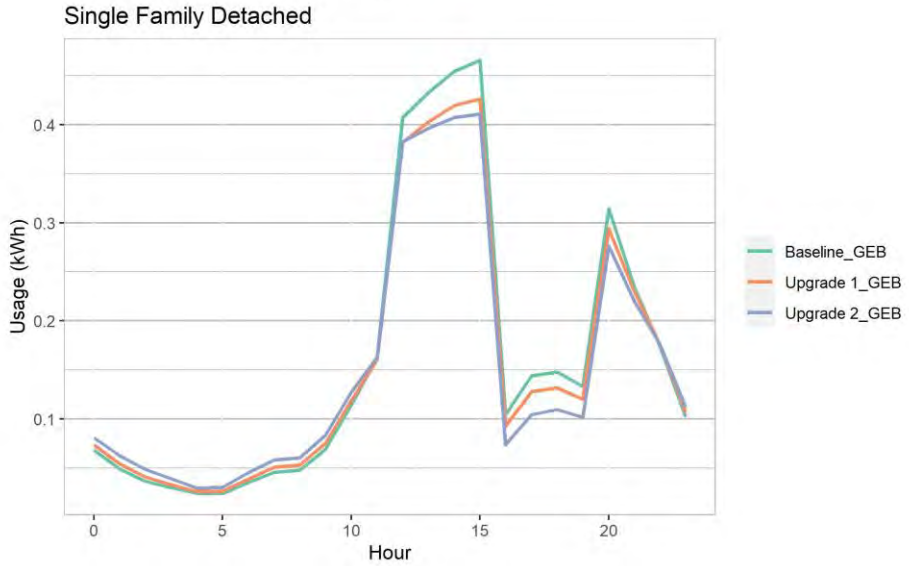


Summer Daily Usage – Climate Zone 5A

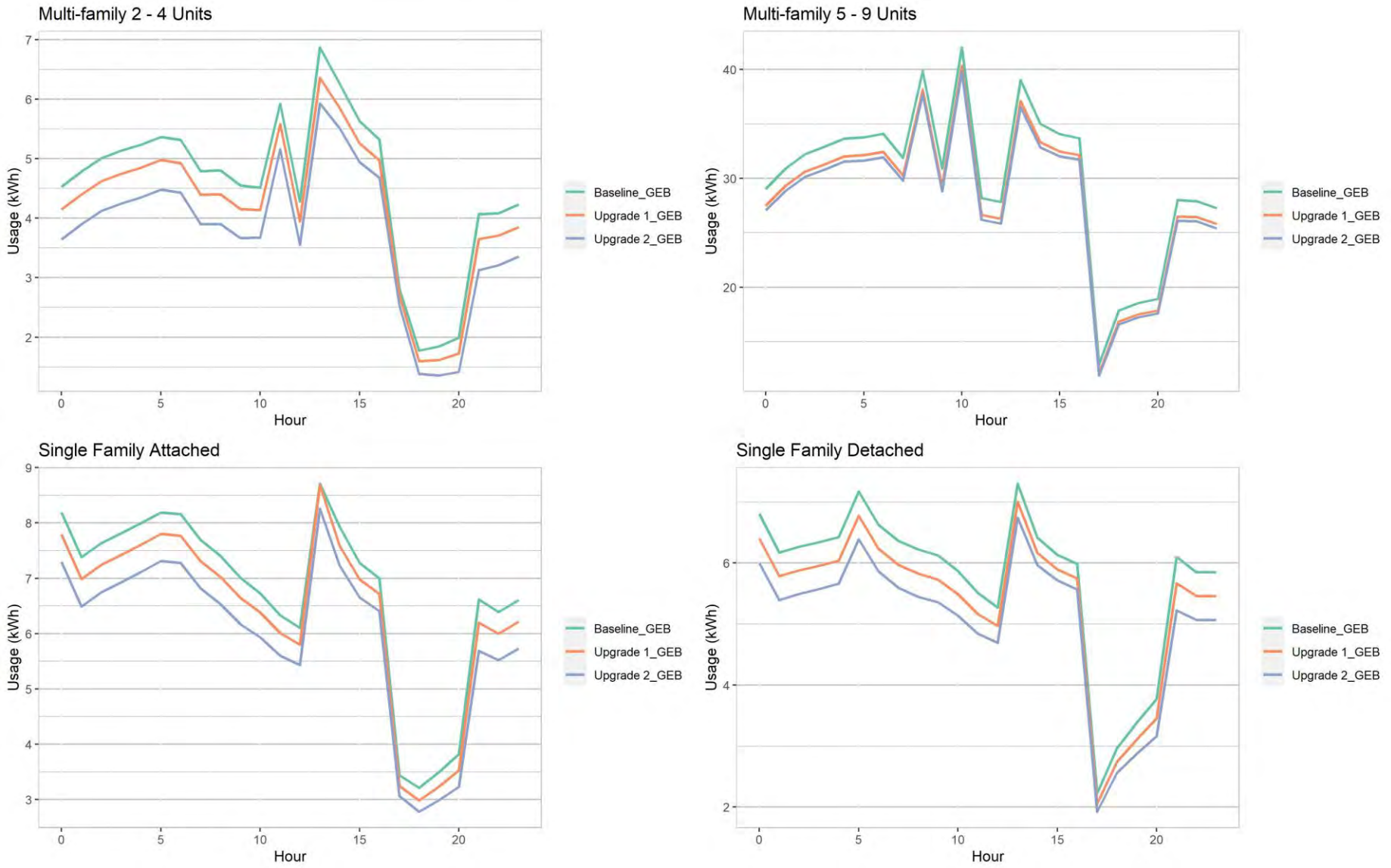




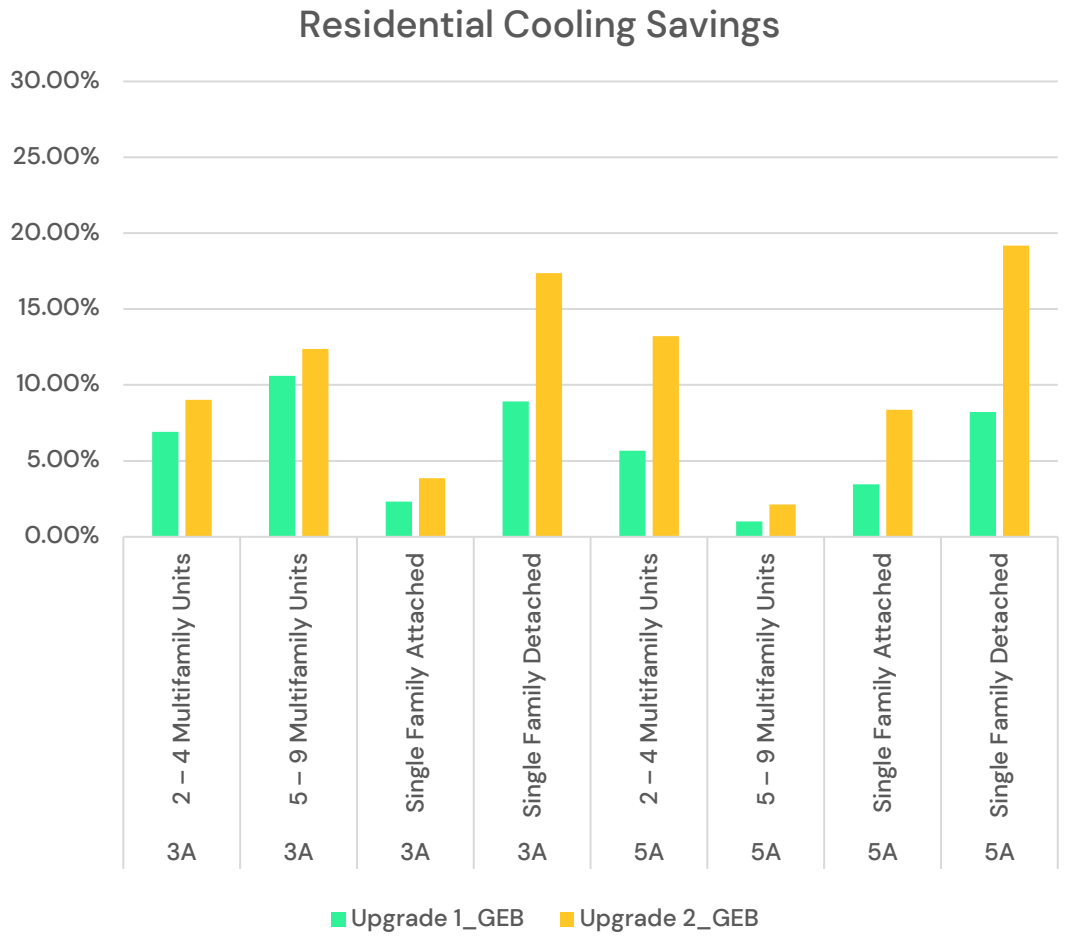


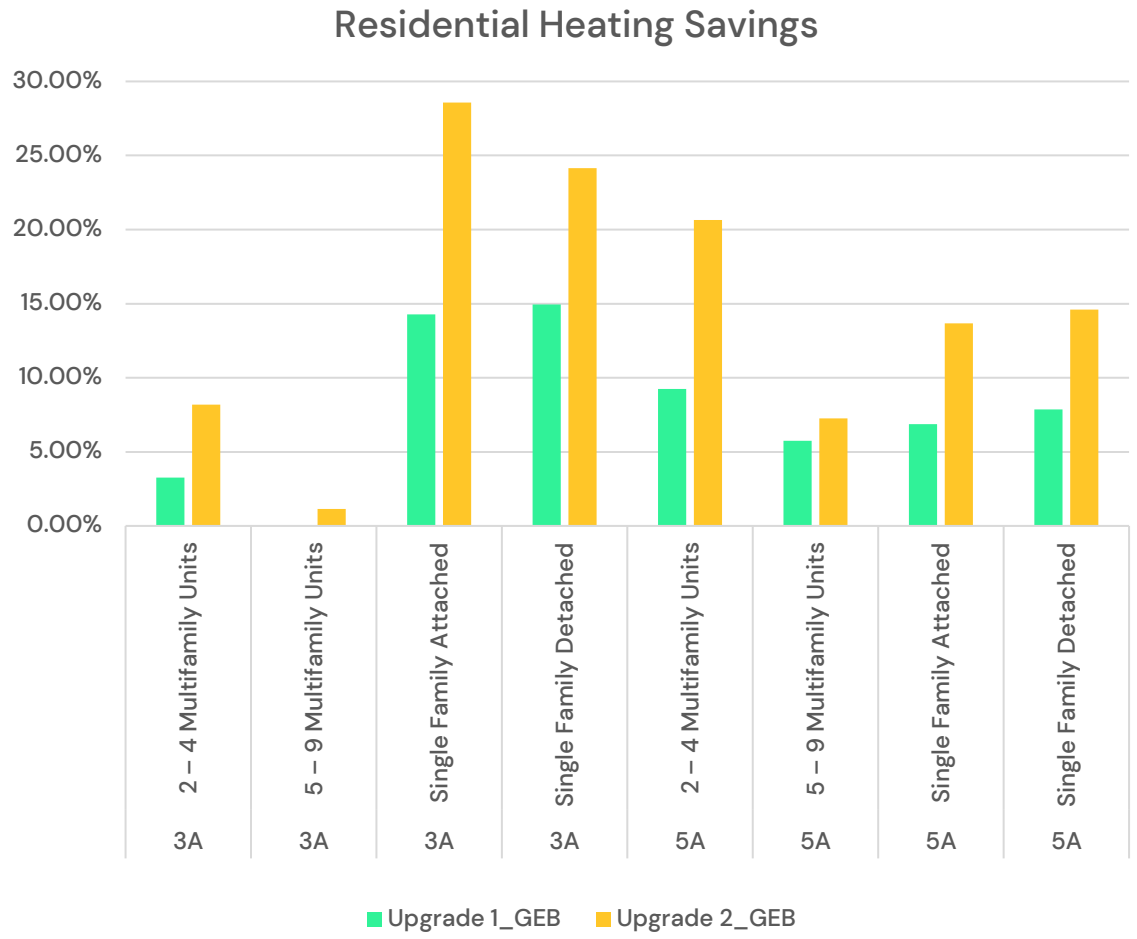


Winter Daily Usage – Climate Zone 5A



Residential Peak Period Usage Reduction





Key Takeaways – Cost Effectiveness

- Homes in climate zones 3A and 5A show diverse results with varied degree of energy usage response to insulation upgrades and adoption of GEB technologies
- Results show that increasing insulation levels in homes, with the selected GEB, is not always cost-effective; but always shows demand savings during the peak hours
- In climate zone 3A –
  - Adding insulation to homes without the GEB is cost-effective for detached single family homes and multifamily homes comprising up to 4 units
  - Adding insulation to homes with GEB is not cost-effective except for detached single-family homes
- In climate zone 5A –
  - Adding insulation to homes with or without GEB is cost-effective and show an increasing levels of cost-effectiveness with increasing insulation, for the scenarios considered. The uptrend can be attributed to higher trapped heat inside homes because of better insulation resulting in higher energy savings and a positive discounted return on insulation investment

Economic Evaluation – Residential Insulation + GEB: Climate Zone 3A

Baseline: Homes with Typical Insulation and GEB Technology

Climate Zone	Building	Upgrade + GEB	LCOE* ($/MWh)
3A	2 – 4 Multifamily Units	Average Insulation	(358.69)
3A	5 – 9 Multifamily Units	Average Insulation	(200.08)
3A	Single Family Attached	Average Insulation	(398.20)
3A	Single Family Detached	Average Insulation	90.67
3A	2 – 4 Multifamily Units	High Insulation	(239.20)
3A	5 – 9 Multifamily Units	High Insulation	(229.95)
3A	Single Family Attached	High Insulation	(229.03)
3A	Single Family Detached	High Insulation	85.91

*Positive LCOE : The insulation + GEB upgrade has a net benefit rather than cost

Economic Evaluation – Residential Insulation + GEB: Climate Zone 5A

Baseline: Homes with Typical Insulation and GEB Technology

Climate Zone	Building	Upgrade + GEB	LCOE ($/MWh)
5A	2 – 4 Multifamily Units	Average Insulation	37.92
5A	5 – 9 Multifamily Units	Average Insulation	51.28
5A	Single Family Attached	Average Insulation	12.91
5A	Single Family Detached	Average Insulation	49.88
5A	2 – 4 Multifamily Units	High Insulation	64.37
5A	5 – 9 Multifamily Units	High Insulation	54.69
5A	Single Family Attached	High Insulation	62.64
5A	Single Family Detached	High Insulation	60.13

Economic Evaluation – Residential Insulation: Climate Zone 3A

Baseline: Homes with Typical Insulation

Climate Zone	Building	Upgrade	LCOE* ($/MWh)
3A	2 – 4 Multifamily Units	Average Insulation	39.17
3A	5 – 9 Multifamily Units	Average Insulation	(2,288.90)
3A	Single Family Attached	Average Insulation	(68.91)
3A	Single Family Detached	Average Insulation	36.50
3A	2 – 4 Multifamily Units	High Insulation	28.13
3A	5 – 9 Multifamily Units	High Insulation	(1,699.28)
3A	Single Family Attached	High Insulation	(42.11)
3A	Single Family Detached	High Insulation	31.14

Economic Evaluation – Residential Insulation: Climate Zone 5A

Baseline: Homes with Typical Insulation

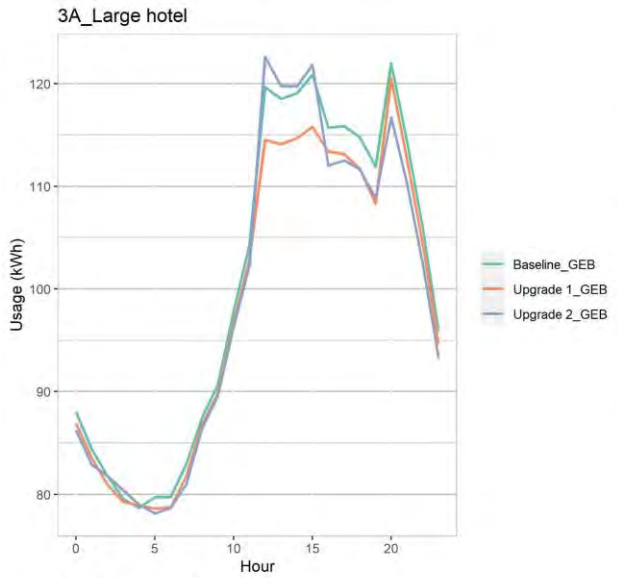
Climate Zone	Building	Upgrade	LCOE ($/MWh)
5A	2 – 4 Multifamily Units	Average Insulation	36.41
5A	5 – 9 Multifamily Units	Average Insulation	51.54
5A	Single Family Attached	Average Insulation	14.22
5A	Single Family Detached	Average Insulation	49.31
5A	2 – 4 Multifamily Units	High Insulation	64.04
5A	5 – 9 Multifamily Units	High Insulation	54.85
5A	Single Family Attached	High Insulation	62.90
5A	Single Family Detached	High Insulation	61.06

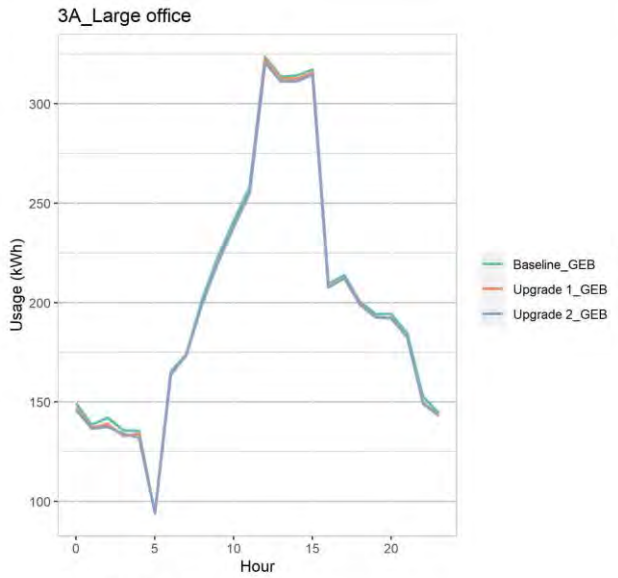
Commercial

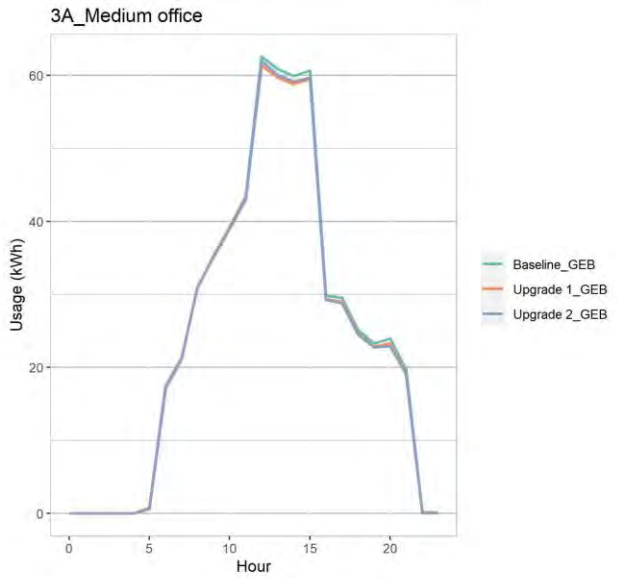
Key Takeaways – Daily Usage Reduction

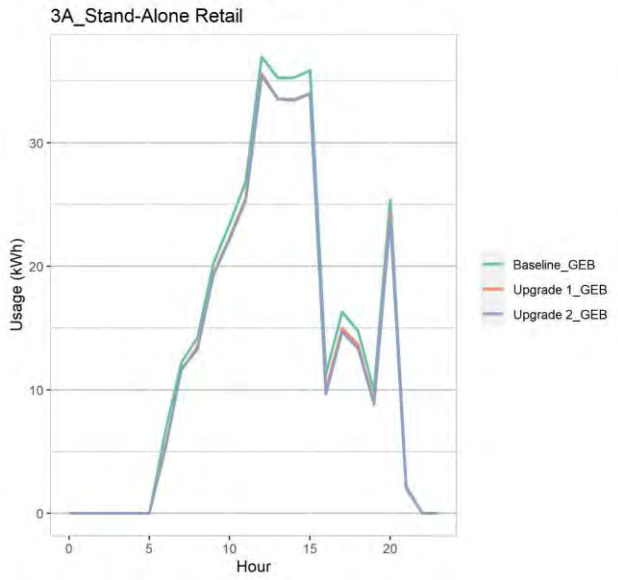
- The charts further display the effect of higher insulation levels on daily usage during summer and winter season, with Upgrade 1_GEB and Upgrade 2_GEB signifying the simulation cases with improved insulation and an implemented GEB technology
- Following the paradigm in the GEB Roadmap, commercial buildings pre-cooled for 4 hours before the peak period at 73F implementing a 2F reduction in setpoint temperature. However, pre-heating is not implemented in commercial buildings
  - A lower pre-cooling level than residential buildings and a setpoint temperature at 80F for the peak period is attributed to the fact that people leaving offices in the later part of the peak period (4-8) PM results in lesser internal heat gain and assisting in retaining the comfort levels of the building longer than expected.
- Results show a usage reduction for typical days during summer and winter seasons; the usage reduction is escalated during the peak usage hours
  - Highest reduction in cooling energy is seen in warehouses at ~10% while the lowest reduction is observed in large office at ~1% for level 1 upgrade.
  - Heating energy reductions during peak period vary between ~18% for stand alone retail while large hotels have the least reduction at less than 2%.

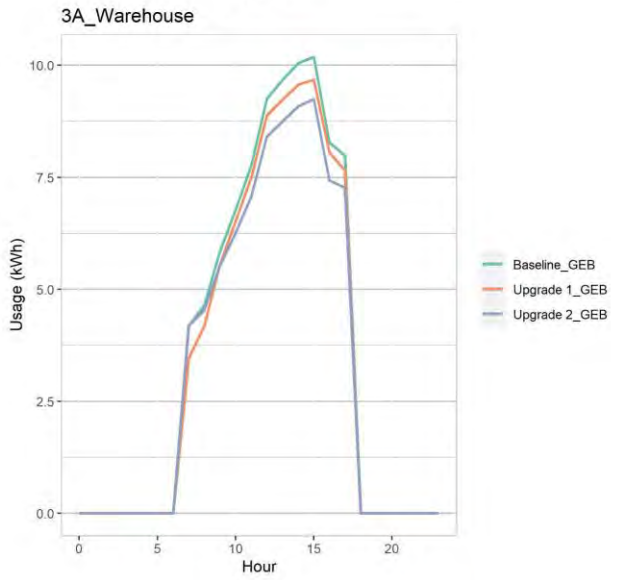
Summer Daily Usage – Climate Zone 3A



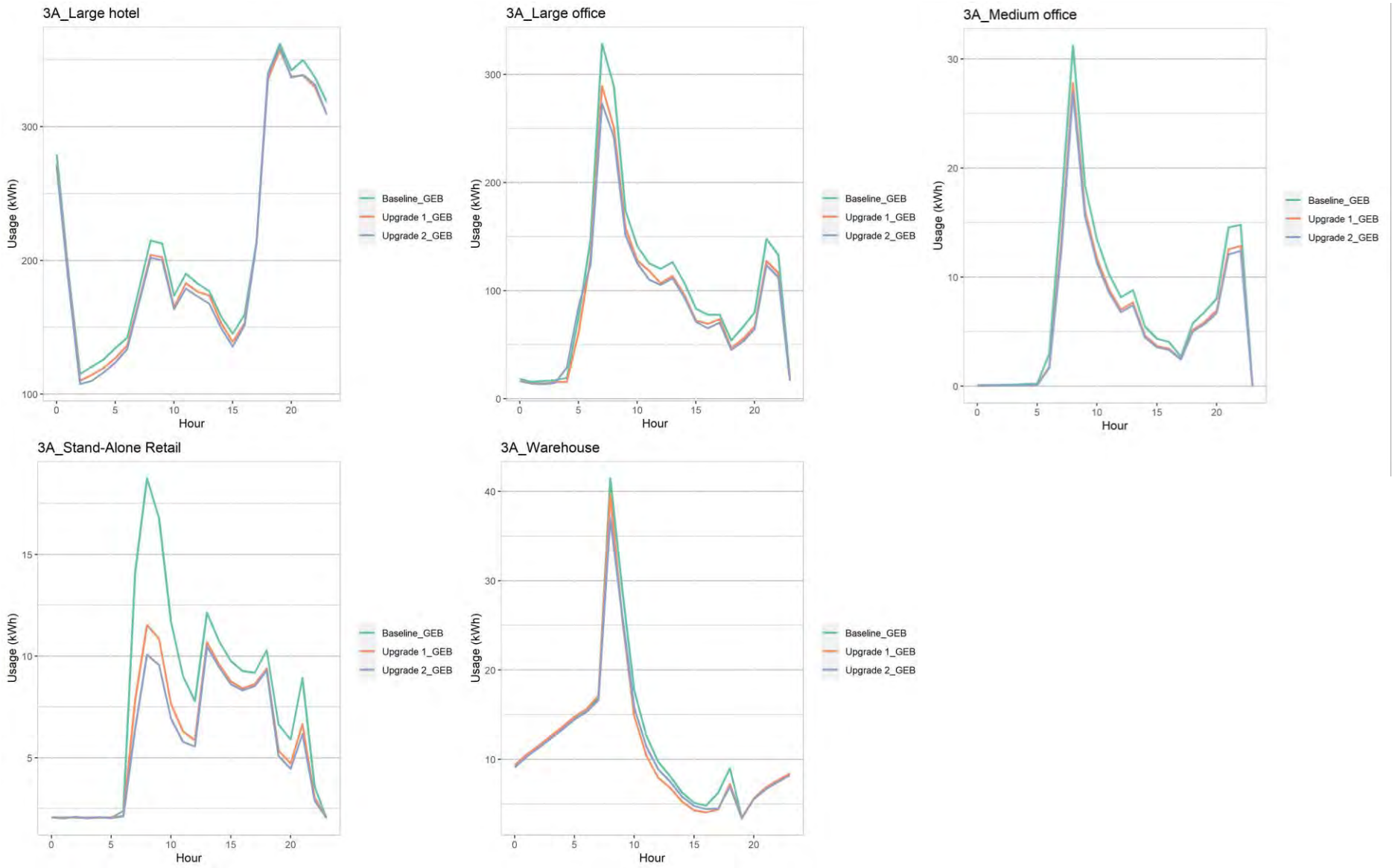




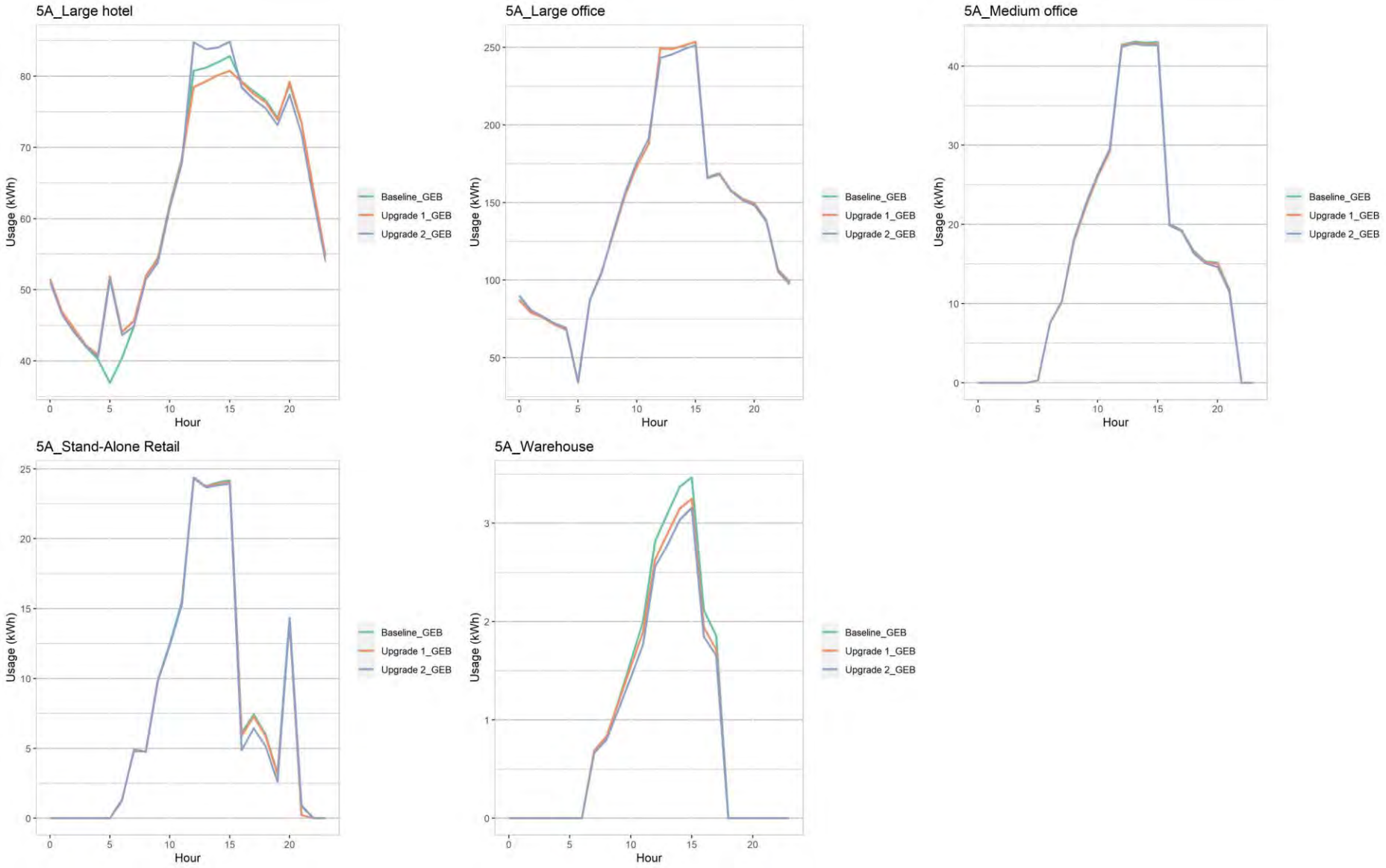




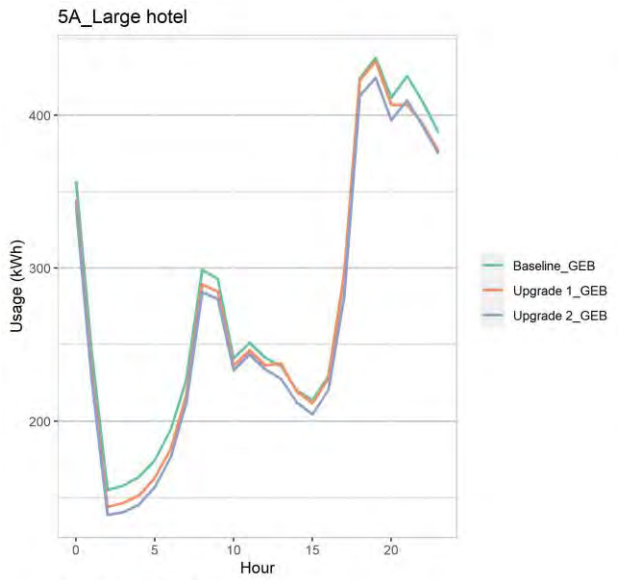
Winter Daily Usage – Climate Zone 3A

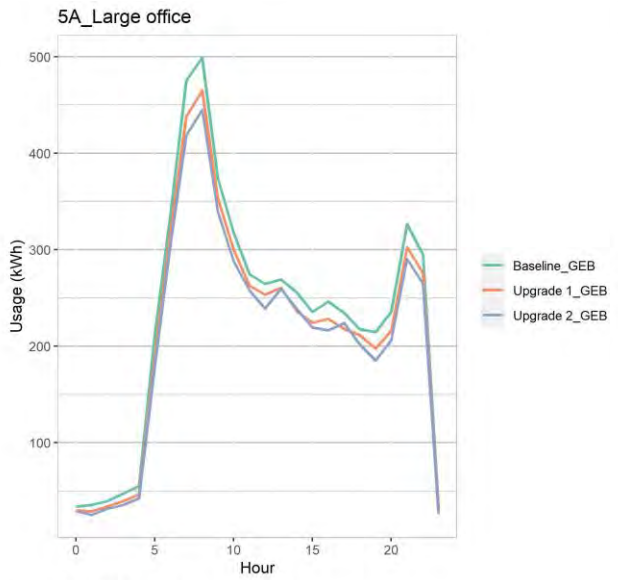


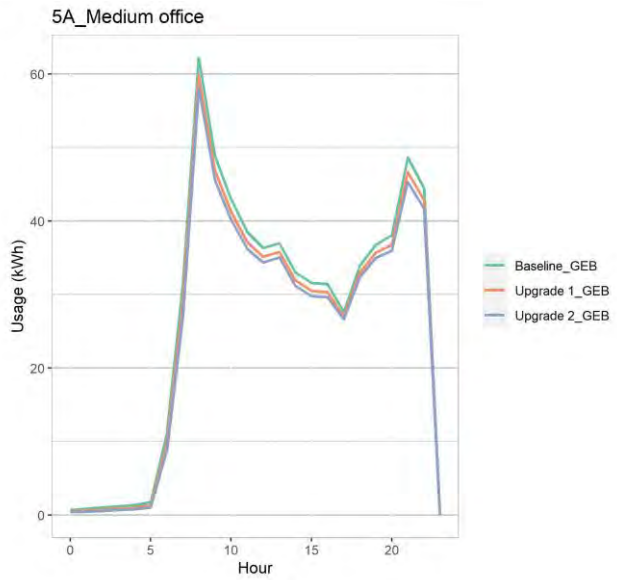
Summer Daily Usage – Climate Zone 5A

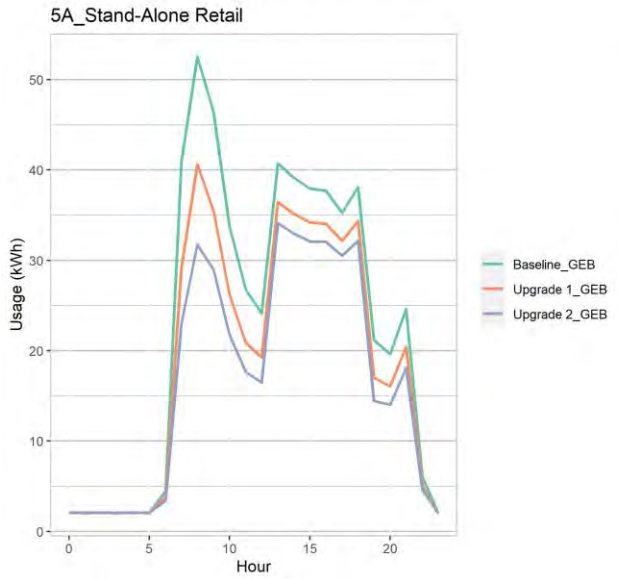


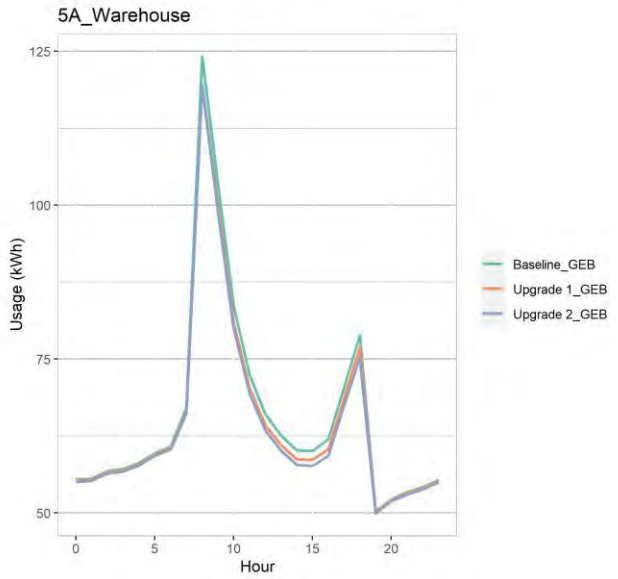
Winter Daily Usage – Climate Zone 5A



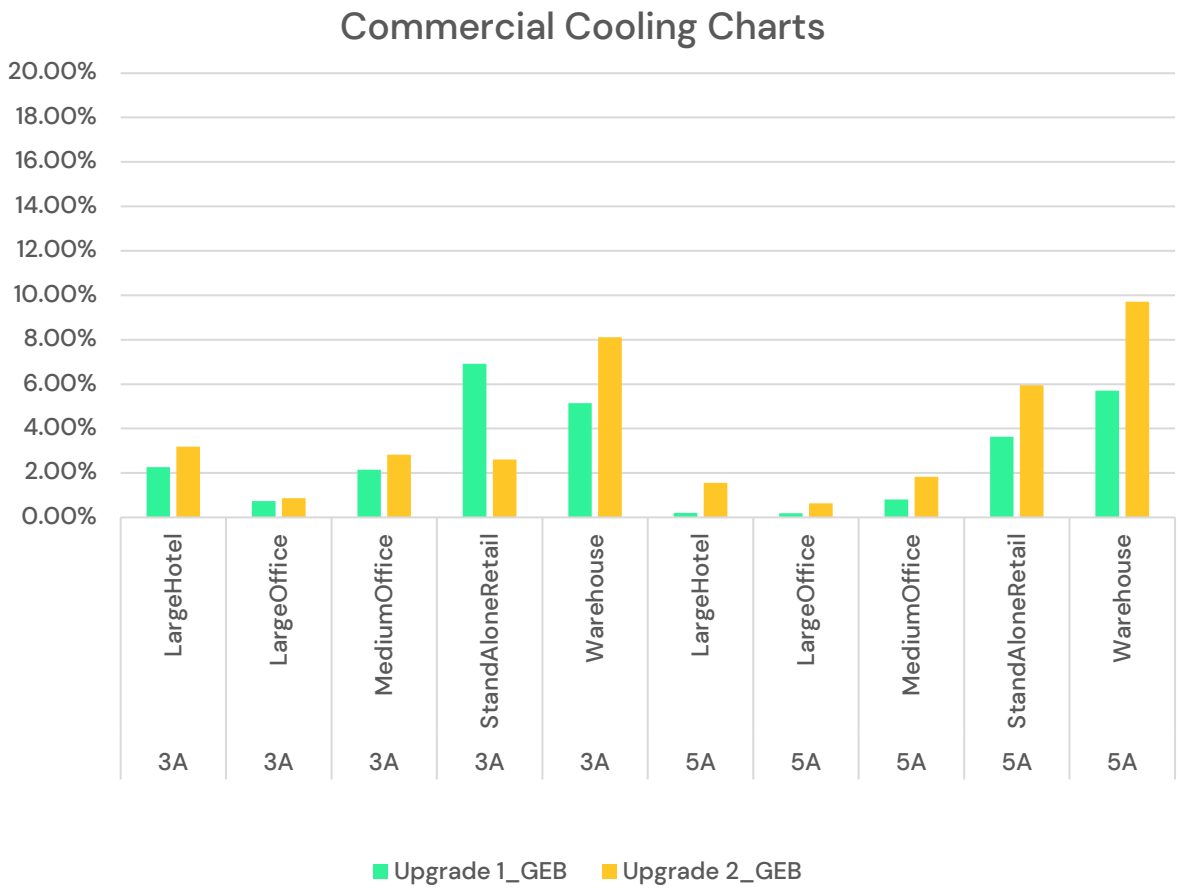


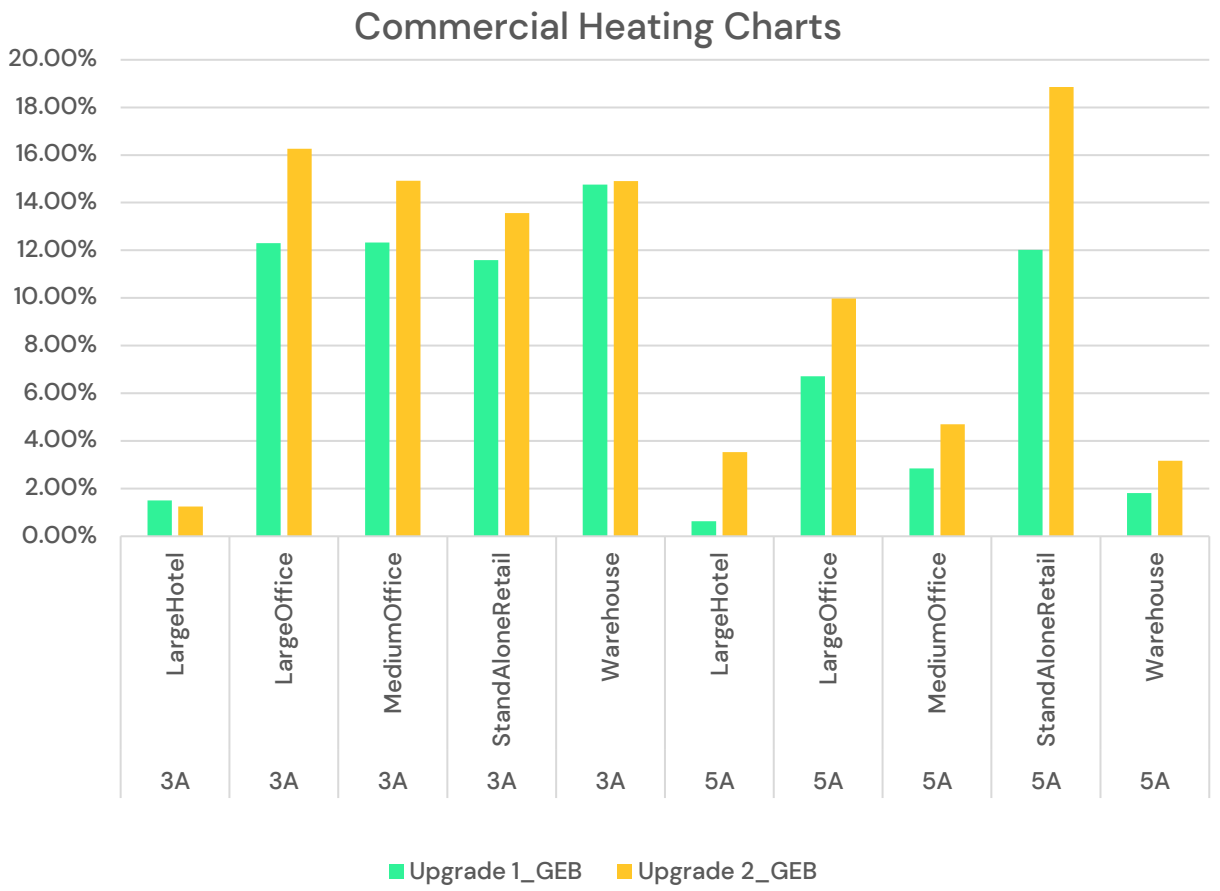






Commercial Peak Period Usage Reduction





Key Takeaways – Cost Effectiveness

- The tables ahead display the cost effectiveness of higher insulation levels installed in commercial buildings across climate zone 3A and 5A
- Commercial buildings with in-built temperature adjustment technology tend to be not cost effective for increased levels of insulation with large hotels and large offices cost effective only.
- In climate zone 3A
  - Cost-effectiveness of buildings in LCOE terms decreases in magnitude as insulation level improves
  - Buildings overall show a muted response to insulation in terms of cost effectiveness particularly in climate zone 3A
  - Typical large offices in climate zone 3A present cost-effective opportunities for multiple levels of wall and roof insulation upgrades
- In climate zone 5A
  - The cost effectiveness improves as insulation level is upgraded
  - Commercial buildings in climate zone 5A typically respond better and present cost-effective opportunities to a greater extent than climate zone 3A
  - Typical warehouses, medium offices and large hotels present limited cost-effective opportunities in climate zone 5A.
  - Large Offices in climate zone 5A are slightly non cost-effective, however, a location specific detailed energy audit can present cost-effective insulation upgrade opportunities

Economic Evaluation – Commercial Insulation + GEB: Climate Zone 3A

Baseline: Commercial facilities with Typical Insulation and GEB Technology

Climate Zone	Building	Upgrade	LCOE ($/MWh)
3A	Warehouse	Average Insulation	(219.17)
3A	Large Hotel	Average Insulation	(15.45)
3A	Large office	Average Insulation	(18.36)
3A	Medium office	Average Insulation	(219.11)
3A	Stand-Alone Retail	Average Insulation	(140.75)
3A	Warehouse	High Insulation	(235.43)
3A	Large Hotel	High Insulation	(36.28)
3A	Large office	High Insulation	14.09
3A	Medium office	High Insulation	(193.31)
3A	Stand-Alone Retail	High Insulation	(180.68)

Economic Evaluation – Commercial Insulation + GEB: Climate Zone 5A

Baseline: Commercial facilities with Typical Insulation and GEB Technology

Climate Zone	Building	Upgrade	LCOE ($/MWh)
5A	Warehouse	Average Insulation	(221.24)
5A	Large Hotel	Average Insulation	5.30
5A	Large office	Average Insulation	(15.78)
5A	Medium office	Average Insulation	(185.41)
5A	Stand-Alone Retail	Average Insulation	(33.15)
5A	Warehouse	High Insulation	(138.44)
5A	Large Hotel	High Insulation	17.62
5A	Large office	High Insulation	4.10
5A	Medium office	High Insulation	(128.29)
5A	Stand-Alone Retail	High Insulation	(7.30)

Economic Evaluation – Commercial Insulation: Climate Zone 3A

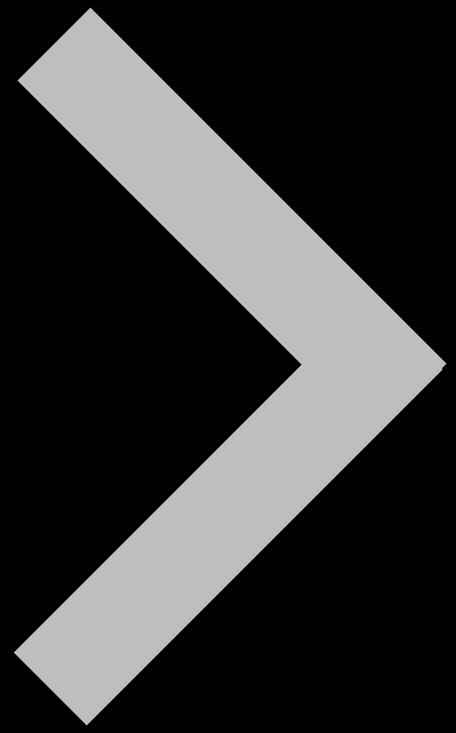
Baseline: Commercial facilities with Typical Insulation

Climate Zone	Building	Upgrade	LCOE ($/MWh)
3A	Warehouse	Average Insulation	(277.42)
3A	Large Hotel	Average Insulation	(9.03)
3A	Large office	Average Insulation	38.61
3A	Medium office	Average Insulation	(160.63)
3A	Stand-Alone Retail	Average Insulation	(140.02)
3A	Warehouse	High Insulation	(381.89)
3A	Large Hotel	High Insulation	(13.87)
3A	Large office	High Insulation	34.01
3A	Medium office	High Insulation	(154.48)
3A	Stand-Alone Retail	High Insulation	(180.09)

Economic Evaluation – Commercial Insulation: Climate Zone 5A

Baseline: Commercial facilities with Typical Insulation

Climate Zone	Building	Upgrade	LCOE ($/MWh)
5A	Warehouse	Average Insulation	31.71
5A	Large Hotel	Average Insulation	6.15
5A	Large office	Average Insulation	(11.57)
5A	Medium office	Average Insulation	(106.27)
5A	Stand-Alone Retail	Average Insulation	(38.85)
5A	Warehouse	High Insulation	(7.08)
5A	Large Hotel	High Insulation	23.67
5A	Large office	High Insulation	4.70
5A	Medium office	High Insulation	36.73
5A	Stand-Alone Retail	High Insulation	(4.72)



Conclusions

Conclusions

- Residential sector offers cost-effective opportunities to a greater extent than commercial sector
- Heating savings are usually realized to a greater extent than cooling savings
- Buildings with pre-implemented GEB technology (temperature adjustments during peak) are generally not cost-effective with a few exceptions
- Climate zone characteristics have a large impact on cost effectiveness of insulation upgrades with extreme climate presenting multiple opportunities than balanced climate regions
- Prevalent residential sector insulation in severe climates, as sourced from RECS supported Resstock database, responds better to insulation upgrades
- Implementation of insulation upgrades assists in reducing peak hour load and present a potential to impact the system level load when implemented across a utility service territory

Get in touch with us:

Haider Khan

Senior Director
703-934-3868
Haider.Khan@icf.com

icf.com

linkedin.com/company/icf-international/

twitter.com/icf

https://www.facebook.com/ThisIsICF/

About ICF

ICF (NASDAQ:ICFI) is a global consulting and digital services company with over 7,000 full- and part-time employees, but we are not your typical consultants. At ICF, business analysts and policy specialists work together with digital strategists, data scientists and creatives. We combine unmatched industry expertise with cutting-edge engagement capabilities to help organizations solve their most complex challenges. Since 1969, public and private sector clients have worked with ICF to navigate change and shape the future.

Residential Insulation Upgrades – Wall

Climate Zone	Building	Baseline	Upgrade 1	Upgrade 2
3A	Single-Family Attached	CMU*, 6-in Hollow, R-11	CMU, 6-in Hollow, R-15	CMU, 6-in Hollow, R-20
	Single-Family Detached	Wood Stud, R-7	Wood Stud, R-13	Wood Stud, R-15
	Multi-Family with 2 - 4 Units	CMU, 6-in Hollow, R-7	CMU, 6-in Hollow, R-13	CMU, 6-in Hollow, R-15
	Multi-Family with 5+ Units	CMU, 6-in Hollow, R-11	CMU, 6-in Hollow, R-15	CMU, 6-in Hollow, R-20
5A	Single-Family Attached	Wood Stud, R-7	Wood Stud, R-13	Wood Stud, R-15
	Single-Family Detached	Wood Stud, R-7	Wood Stud, R-13	Wood Stud, R-15
	Multi-Family with 2 - 4 Units	Wood Stud, R-7	Wood Stud, R-13	Wood Stud, R-15
	Multi-Family with 5+ Units	CMU, 6-in Hollow, R-7	CMU, 6-in Hollow, R-13	CMU, 6-in Hollow, R-15

* Concrete Masonry Unit

Residential Insulation Upgrades – Roof

Climate Zone	Building	Baseline	Upgrade 1	Upgrade 2
3A	Single-Family Attached	Ceiling R-20, Vented	Ceiling R-30, Vented	Ceiling R-38, Vented
	Single-Family Detached	Ceiling R-13, Vented	Ceiling R-30, Vented	Ceiling R-38, Vented
	Multi-Family with 2 - 4 Units	R-30	R-38	R-49
	Multi-Family with 5+ Units	R-30	R-38	R-49
5A	Single-Family Attached	Ceiling R-38, Vented	Ceiling R-49, Vented	Ceiling R-60, Vented
	Single-Family Detached	Ceiling R-20, Vented	Ceiling R-30, Vented	Ceiling R-38, Vented
	Multi-Family with 2 - 4 Units	R-30	R-38	R-49
	Multi-Family with 5+ Units	R-30	R-38	R-49

Commercial Insulation Upgrades - Wall

Climate Zone	Building	Baseline	Upgrade 1	Upgrade 2
3A	Warehouse	R-10	R-15	R-20
	Large Hotel	R-7	R-15	R-20
	Medium Office	R-12	R-20	R-23
	Large Office	R-7	R-15	R-20
	Standalone Retail	R-7	R-15	R-20
5A	Warehouse	R-20	R-23	R-30
	Large Hotel	R-10	R-15	R-21
	Medium Office	R-17	R-23	R-30
	Large Office	R-10	R-15	R-21
	Standalone Retail	R-10	R-15	R-21

Commercial Insulation Upgrades – Roof

Climate Zone	Building	Baseline	Upgrade 1	Upgrade 2
3A	Warehouse	R-24	R-38	R-49
	Large Hotel	R-25	R-38	R-49
	Medium Office	R-25	R-38	R-49
	Large Office	R-25	R-38	R-49
	Standalone Retail	R-25	R-38	R-49
5A	Warehouse	R-26	R-38	R-49
	Large Hotel	R-30	R-38	R-49
	Medium Office	R-30	R-38	R-49
	Large Office	R-30	R-38	R-49
	Standalone Retail	R-30	R-38	R-49