MIT Campus Decarbonization Proposal (V1)

Advanced District Heating and Cooling System with Active Exhaust Energy Recovery & Ground Coupled Thermal Storage

MIT Alumni for Climate Action (MACA) – MIT Campus & Geo@MIT
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Abstract

Of all Scope 1 emissions on MIT’s campus, 97% are from building operations. To help reduce emissions that contribute to global warming, many academic institutions and other building clusters are implementing what is called 4th-Generation Centralized District Energy systems which in general represent the least efficient and highest cost approach to campus decarbonization with heat pumps. Some campuses and many commercial building clusters are implementing 5th Generation Distributed systems which provide greater operational efficiency and resilience typically at lower cost when designed with modern techniques and equipment.

This proposal is to achieve full buildings decarbonization thus zero emissions from buildings by leapfrogging both 4th and 5th generation approaches to the emerging 6th Generation District Heating and Cooling which includes the most cost-effective features of 5th Generation districts plus low cost Ground Coupled Thermal Batteries and advanced AI controls emerging now from DOE labs and industry. These additional advances should further reduce installation costs, and definitely lead to the lowest operational costs by interacting with the grid “market” to coordinate campus power consumption with periods of high Clean Power availability and low power cost. Such systems incorporate all of the following benefits implemented in balance based on cost-effectiveness and rapidly achieving a fully decarbonized campus:

- 100% renewable energy powered;
- Maximal recycling of waste energy from high-volume laboratory exhaust;
- “Active” ambient loop utilizing the existing chilled water piping where present;
- Thermal batteries to provide grid energy time and cost-shifting;
- Eliminates the expenses of a new steel piping distribution system from separate heating and cooling systems;
- Eliminates energy distribution losses and minimizes pumping loads between a Central Utility Plant (CUP) and each building;
- Captures “free energy” from campus-wide concurrent heating and cooling and similarly from recovered exhaust energy;

- Minimizes cost to operations from emerging clean electric-grid variability; and is
- The fastest, least disruptive, and most cost-effective path to MIT Campus decarbonization, and best way to Zero Carbon currently available.

MIT currently has a 3rd Generation campus district energy HVAC system based on Combined Heat and Power (CHP), chilled water, and steam distribution. There is a knowledge jump needed to understand 6th Generation advanced districts systems as they employ heat pumps and thermal batteries in ways very unfamiliar to 3rd Generation experts, but which are already proven by others to be highly cost effective and with low impact when well designed.

To help jump-start the process of decarbonization at MIT, MIT Alumni for Climate Action (MACA) together with an MIT student team "Geo@MIT" designed a "6th Generation District Heating and Cooling with Advanced Thermal System for 100% Decarbonization of the MIT Campus by 2035." This plan was specifically slanted to highlight the "geothermal" ground battery aspects of the approach, but a full understanding of the plan shows it is actually about minimizing the amount of "ground battery" needed and also minimizing campus disruption while maximizing cost-effectiveness and the pace of decarbonization.

The MACA-MIT Campus team members collectively have 160 years of district energy and geothermal experience, and direct industry connections to virtually all the leaders in the building HVAC decarbonization field. The MACA-MIT Campus plan's guiding principles are to:

(i) leverage existing infrastructure as much as possible;
(ii) minimize disruption during the transition period;
(iii) reduce capital and operating expenses where possible.

The resulting design creates a fully inter-operating system under advanced AI-based control meant to represent the least cost to install and operate buildings decarbonization approach available with today's technologies.

The key 6th Generation Advanced District Energy System elements needed for MIT to achieve a zero-carbon emission campus by 2035 are as follows:

1. **Ambient Temperature Water Loop with Heat Pumps (HP)**: Existing extensive campus "chiller loop" infrastructure will be operationally transitioned into an Ambient Loop (45°F-90°F) with efficiency optimized bi-directional HP connections to provide optimal campus-wide energy exchange. HPs, with compressors in buried vaults if needed, would be installed at each campus building to deliver heating and cooling. The Central Utility Plant would provide Ambient Loop supplemental thermal and circulation control. Planned high-cost hot water upgrades will be avoided.

2. **Active Heat Pump-based Energy Recovery Ventilation (ERV)**: Ambient Loop connected Heat Pumps will be installed in all building exhaust systems to achieve nearly 100% exhaust energy recovery, with special emphasis on labs, scaled for and seamlessly upgrading existing exhaust systems, and designed to enable cost-effective air source heat pump (ASHP) overdrive on exhaust streams during periods of suitable outdoor air temperatures and low cost grid power.

3. **Upgraded Forced Air Systems**: upgrade all existing cold air distribution systems to ambient loop coupled efficient HPs providing both heating and cooling w/active reheat & minimized terminal reheat. Add perimeter supplemental HP terminal units if needed in older buildings.
4. **Distributed Thermal Energy Storage**: As the electrical grid incorporates more renewable sources, storage will be required to manage intermittency and cost variability. Advanced ground-coupled Thermal Battery energy storage systems will take advantage of MIT's fully saturated coastal estuary soil makeup to provide cost-effective energy storage. The proposed Thermal Batteries are for daily, weekly and grid-cost control, resulting in a lower Levelized Cost of Storage (LCOS) than battery-storage alternatives, and providing capacity and cost resilience for any extreme weather or high power cost periods.
5. **Innovative Ground Heat Exchanger (GHEX) Drilling Techniques:** Novel very low impact GHEX installation techniques will allow installation deep under parts of the campus on an "as needed" basis for annual system balancing, with the GHEX sized for optimal cost effectiveness. Two advanced techniques are identified.
6. **Municipal Water Distribution Thermal** interconnection and sewer energy recovery/rejection will be used where possible to reduce the need for GHEX drilling – analyzing the available scale of these highly cost-effective 5th and 6th Generation elements is underway now by the MACA team.

The joint MACA Alumni + Geo@MIT student team presents this MIT Campus Decarbonization Proposal to the wider MIT community and welcomes the opportunity to partner with the MIT Administration in its efforts to decarbonize the MIT campus, beginning in 2024-2025. Please note that this presentation as originally written was specifically for a "geothermal" centric approach although the as-presented system is in fact a geothermal-minimalist 6th Generation plan, with cost-effectiveness plus pace of decarbonization plus minimal campus disruption being the central driving principals.

1. Site Identification

Overview:

MIT's campus in Cambridge, MA (yellow outline, Figure 1.1) is ideal for deploying an advanced ground coupled heating and cooling system, with an initial focus on the buildings in blue which are served by the existing Central Plant Chiller Water (CW) Loop.

The campus encompasses 168 acres extending more than a mile along the Charles River basin. The campus is urban and walkable, with more than 40 gardens and green spaces. All campus heating and cooling (HVAC) energy is currently provided from a Central Utility Plant (CUP) by natural gas powered Combined Heat and Power (CHP) and boilers, plus steam and electric chillers. Steam and chilled water are transmitted from the CUP to campus buildings through an extensive pipe distribution system.

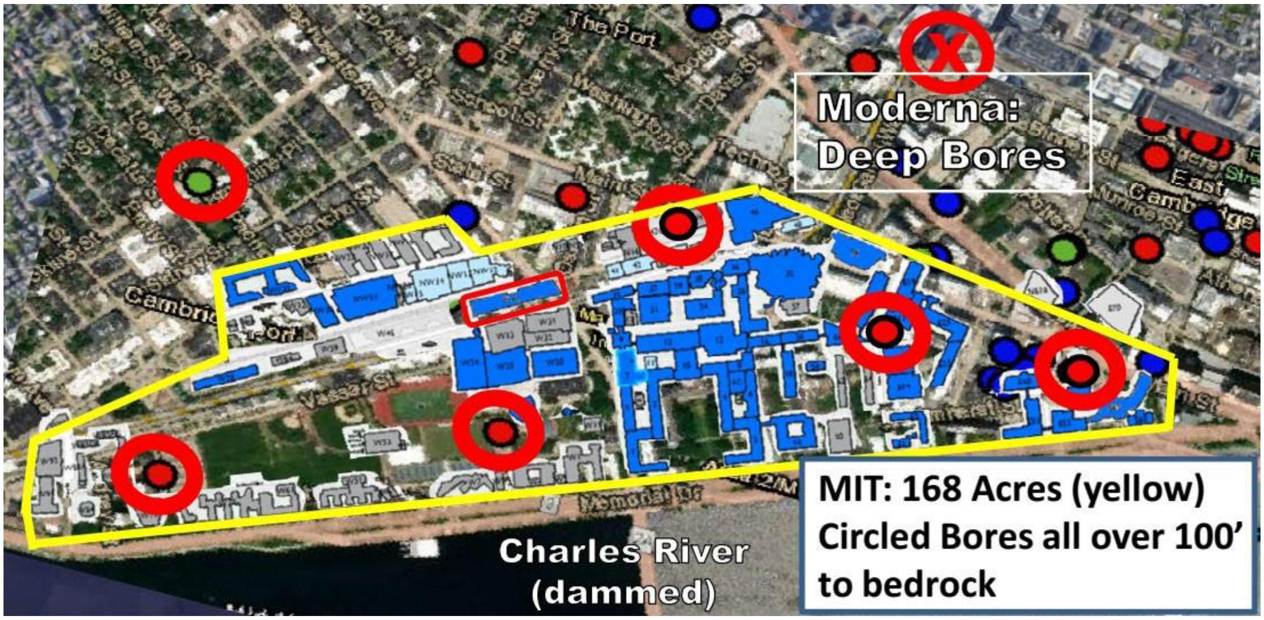


Figure 1.1: Map of the MIT Campus, existing Chiller Loop buildings (blue), analyzed bore hole data (red).[1][3]

MIT has 43 completed and 50 in-progress energy efficiency projects. Three projects achieved LEED-Platinum certification and 18 LEED-Gold certification. The campus is composed principally of a West Campus with athletic facilities, dining halls, and most residential dorms, and an East Campus with classrooms, labs, and research centers. The Met Building conversion (177,000 sq.ft, rectangular box in red) is the first MIT building with Water Source Heat Pumps using the Chilled Water Loop return line to produce heat only.

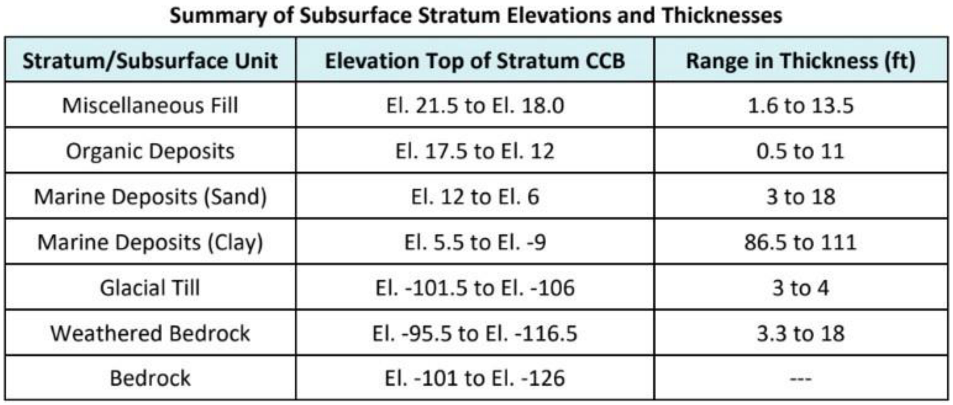
MIT has committed to decarbonization, yet currently plans on a 4th Generation Central Plant approach with a costly Hot Water upgrade requiring an extensive Steel Pipe Loop addition. The proposed District Heating and Cooling System, presented here as a Geothermal District Heating and Cooling (GDHC) system which actually employs several heat pump advances including "geothermal", could accelerate MIT's decarbonization 15 years ahead of schedule, almost certainly at a lower overall cost of decarbonization. Furthermore, 40% or more of the GDHC system conversion cost can right now be paid for through the Inflation Reduction Act (IRA) Tax Credits and Massachusetts State Tax incentives for renewable energy and energy efficiency making a GDHC system almost certainly far more cost-efficient than any other decarbonization approach.

Justification of Site Selection:

The MIT Office of Sustainability states that 97% of Scope 1 emissions are from the natural gas CHP-based CUP plant and regional electric grid emissions[1]. A GDHC system will leverage the consistent ground temperatures to provide the most efficient heating and cooling, eliminate direct carbon emissions, and eventually all emissions once the connected regional grid is clean power. The existing CW loop provides an ideal opportunity for highly cost-effective GDHC implementation.

2. Geothermal Resource Assessment

History, Geography, Topography of Site: Historic maps indicate the area now occupied by the MIT Campus was previously Charles River Basin marshland. By 1899, the land under MIT was filled for site development with silt, sand, gravel, ashes, and other city waste. The physical geology of Cambridge dates the Boston Basin from the Cambrian to Proterozoic era and comprises pelitic rock.[4] The Undisturbed Ground Temperature is about 51.5°F[5][6]. Numerous geotechnical reports[4] and an MIT commissioned study[5] confirm the underlying bedrock is Cambridge Argillite and the overburden is mostly Boston Marine Clay to over 100’. The clay deposits are fully saturated (adjacent dammed river) and mostly soft with some sand and a little rock or gravel, thus providing excellent thermal exchange and low-cost drilling ([7], Figure 2.1). This soil likely has a reliable Heat Capacity (HC) = 62 BTU/(cuft-°F) and a Thermal Conductivity just under 1.0 BTU/(ft-hr-°F) – an Advanced Thermal Conductivity Test will be required to determine the precise figures.[9] Deeper geothermal drilling at the Moderna building just NE of MIT showed the Argillite is very fragile, requiring special, more expensive drilling techniques and/or the use of appropriately experienced and outfitted drillers.



Summary of Subsurface Stratum Elevations and Thicknesses

Stratum/Subsurface Unit	Elevation Top of Stratum CCB	Range in Thickness (ft)
Miscellaneous Fill	El. 21.5 to El. 18.0	1.6 to 13.5
Organic Deposits	El. 17.5 to El. 12	0.5 to 11
Marine Deposits (Sand)	El. 12 to El. 6	3 to 18
Marine Deposits (Clay)	El. 5.5 to El. -9	86.5 to 111
Glacial Till	El. -101.5 to El. -106	3 to 4
Weathered Bedrock	El. -95.5 to El. -116.5	3.3 to 18
Bedrock	El. -101 to El. -126	---

Figure 2.1: Subsurface Geotechnical reports summary, all fully saturated.

Current Energy and General Infrastructure: Many colleges and other building clusters are implementing 4th Generation Centralized energy systems. MIT currently has a 3rd Generation campus district energy system supported by a Central Utility Plant (CUP) (Figure 2.2) incorporating natural gas turbine Combined Heat and Power (CHP) plus boilers for additional steam distribution, and separate systems for generating chilled water (CW) comprising steam-driven and electric chillers.

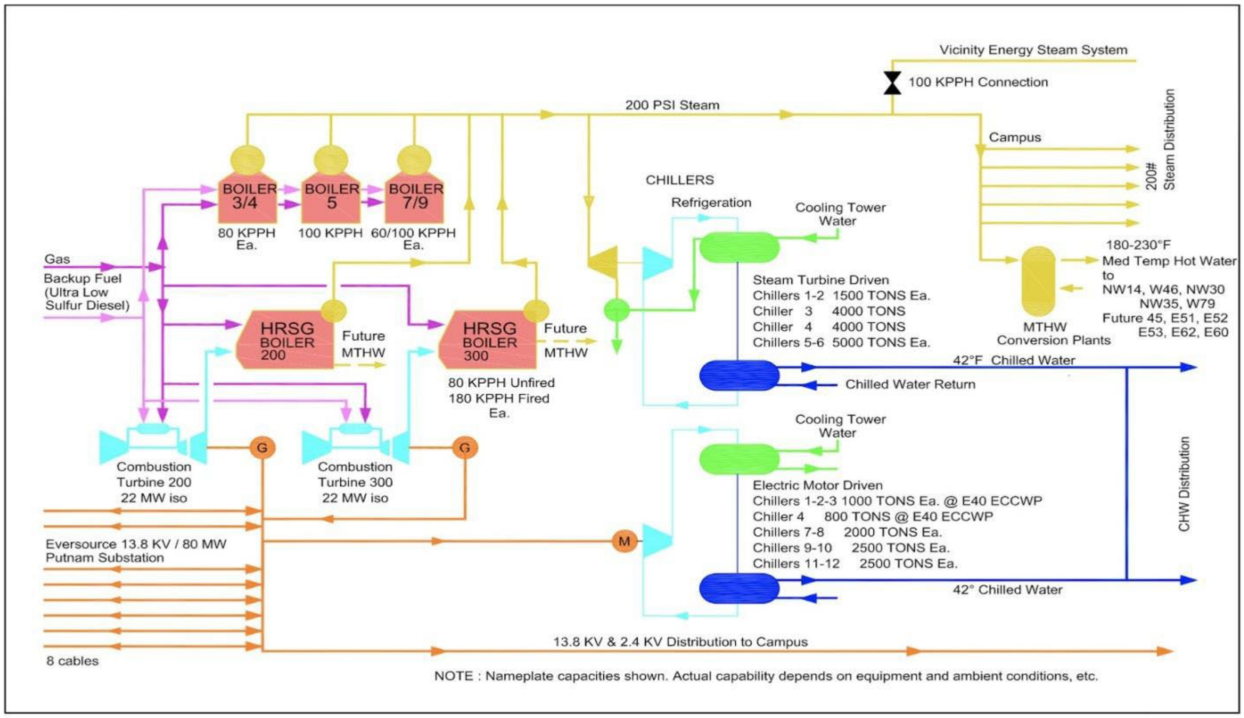


Figure 2.2: MIT's Central Utilities Plant infrastructure schematic for heating, cooling, and electricity.

Nearly 70% of MIT's energy consumption and CO_2 emissions are associated with generating steam and chilled water for building HVAC[10]. Additional CO_2 emissions are due to the regional electric power grid. It is reported that 54% of the chilled water produced comes from the less efficient steam-powered compressors - a CHP byproduct. Since heating and cooling operations make up MIT's largest portion of energy needs and greenhouse gas emissions, electrifying these systems and phasing out the use of natural gas is paramount to decarbonizing MIT.

Conversion to GDHC System: Converting the MIT campus to a geothermal district heating and cooling (GDHC) system would eliminate emissions produced for HVAC once 100% Clean Grid Power is available.

Implementing a GDHC requires water source heat pump installation, ground loop installation, and a water distribution system termed an "Ambient Loop" in 5th Generation and later district systems. Existing Steam and CW distribution piping runs throughout MIT's campus. Figure 1.1 (Site Identification above) highlights which buildings currently have CW piping infrastructure[11] – our initial target scope due to ease of conversion. The existing CW piping loop can be directly "transitioned" into an Ambient Loop for a GDHC – the only difference between a CW Loop and an Ambient Loop is the expected temperature range, 45°-54°F for a CW Loop relaxed to 40°-90°F for an Ambient Loop. Utilizing the existing piping infrastructure drastically reduces implementation costs.

Novel Ground Heat Exchanger (GHEX) and Thermal Battery Installation Techniques: Our team has identified novel installation techniques (Figure 2.3) for low-impact ground loop installation based on MIT's local geology and campus density.

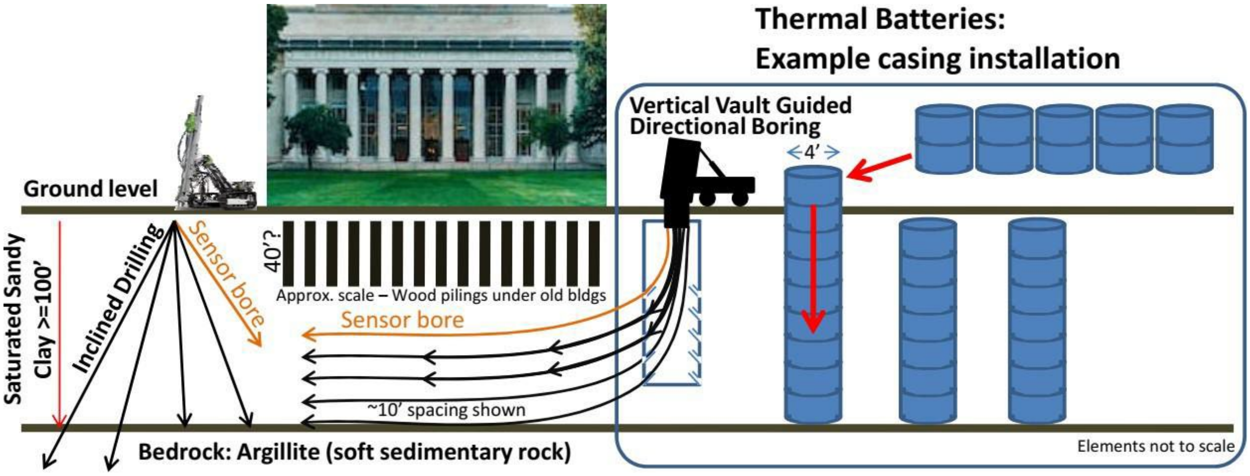


Figure 2.3: Innovative Thermal Battery and Ground Heat Exchanger (GHEX) Installation Techniques

Common overburden Directional Boring techniques will allow careful GHEX placement under most of the campus, with "sensor loops" and special thermal pattern management used in thermally sensitive areas such as under building pilings. ORNL-designed Thermal Batteries[12] (details in Engineering and System Design Assessment below) will be installed as needed, using techniques currently under development that require only 20 sq ft surface space free of buried utilities. The fully saturated soft clay and sedimentary soils under MIT's campus readily support these techniques for areas from 50'-100' deep. The approach, validated by geothermal heat pump industry experts, provides predictable thermal conductivity and reduces the GHEX size needed. Large drilling equipment is not required with soft soils and with a surface area under a 20' radius, with a limited number of locations required to install loops under the whole campus. Star pattern Inclined Drilling techniques, pioneered by Celsius Energy[13], uses simultaneous

Figure 2.4: Drill Sites Map for Inclined Drilling site, coded by size & access (interactive map link:[14]) - sites suitable for Thermal Batteries are everywhere and too many to note

casing rigs suitable for the soft Argillite bedrock formations to drill deeper bores if needed. To confirm the Inclined Drilling's suitability for this site, a test bore is needed due to the fragile bedrock.

A GoogleMap with site photos showing 51 drill sites that meet the larger minimum ~20'x50' work areas that Inclined Drilling requires is shown in Figure 2.4.[14] Both ground thermal approaches are highly compatible with the urban setting and the need to minimize disruption to campus activities, with all the identified approaches fitting virtually everywhere on campus.

Available GHEX Size: Combining all the above and assuming we can only use the bottom 50' of the >100' deep overburden , and further assuming a 20°F annual GHEX ground temperature charge/discharge, we calculate a Thermal Storage capability of the lower 50' of the 168 acres campus to be 168A * 43,560 sqft/A * 60' * 20°F * 62 BTU/(cuft *°F)= 544,465 MBTU (million BTUs). Per the data we have, MIT consumes about 230,000 MBTU after adjusting for the anticipated recovery of exhaust energy, anticipated diversity savings, and adjusting for heat pumps operating at COP=4. Under the proposed upgrades, only 42% of GHEX available space is required (230K/544K) to achieve full annual thermal storage for a GDHC system under MIT's current load. The actual space required for ground thermal storage will almost certainly decline once a detailed numerical model including the use of grid active Thermal Batteries is completed and analyzed.

Geothermal Boring Planned: The GHEX plan, only as needed pursuant to further analysis, is based on directional boring using ~1.5M feet of bore (15' spacing), or about 580 feet of bore per day given the 12-year optimal installation plan. To cover all contingencies, including weather and campus activities, we would expect a 3 site continuous boring plan to be implemented. The small bore sites will be easily hidden, with a low decibel level, and support equipment (mud cleaning, etc) at the closest available parking lot or open space with road access. Only small rigs will be used and all areas would be fully restored. Directional boring will be used to connect each thermal battery/vault/drill site to nearby buildings and the existing Ambient Loop piping. This approach will avoid all the challenges of adding new underground infrastructure via trenching.

3. Engineering and System Design Assessment

Understanding the Thermal Loads and Challenges: MIT campus buildings have varying HVAC loads as shown in Figure 3.1.[15] The significant variations in energy consumption are due to use, with offices requiring the least energy and laboratories the most.

Large labs like Building 76 (built in 2011) with 100% exhaust and make-up air require disproportionately high amounts of energy per sqft, and MIT has many lab buildings and spaces. Despite advances in energy-efficient design that make newer lab buildings less energy intensive, a new lab like Building 76's recovery "heat pipes" still only recovers less than 40% of exhaust energy. It seems obvious that Exhaust Energy Losses clearly represent the largest part of MIT's total HVAC load. Analyses of just three buildings (Bldg 76 lab, Bldg 9 classes/offices, and Bldg E60 offices[16]) showed that exhaust energy losses are sometimes large in non-labs as well. With labs having over 60% exhaust losses and the rest of campus having at least 35% exhaust losses (less-than-perfect ERV style 70% maximum energy recovery), we estimate overall campus exhaust energy losses at about 50% of the total HVAC load, which our solution cost-effectively addresses.

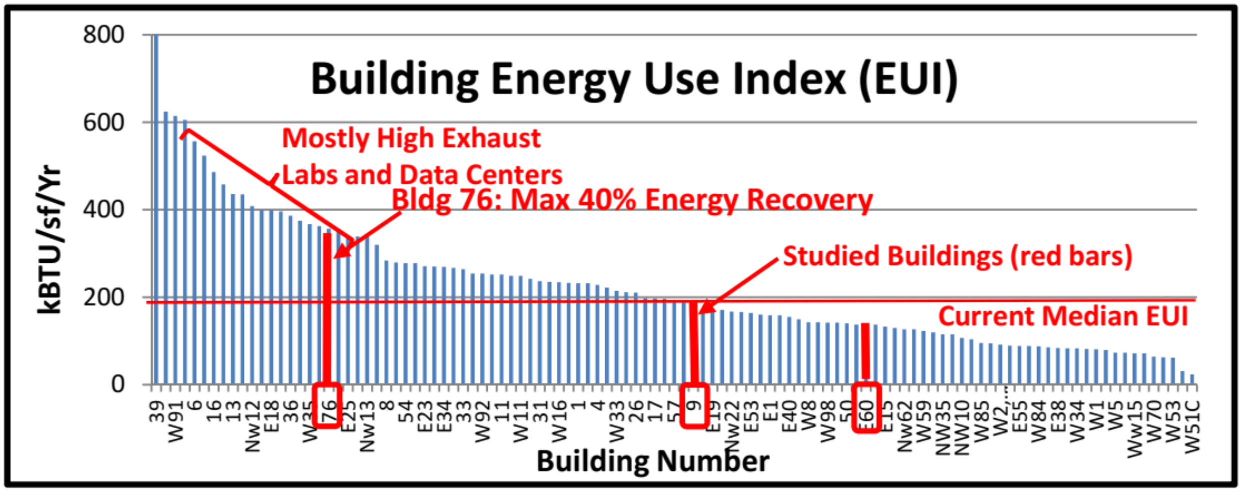


Figure 3.1: Building Energy Use Intensity (EUI) expressed as kBTU/GSF/year.[1]

Weather patterns also affect the building energy loads, but the weather at MIT is coastal and relatively mild for New England with the closest weather station (Figure 3.2)[3] having few hours <20°F. Figure 3.3[4] shows a typical whole campus load graph where one can see that the loads highly track weather patterns demonstrating how much energy is used for exhaust/make-up air conditioning.

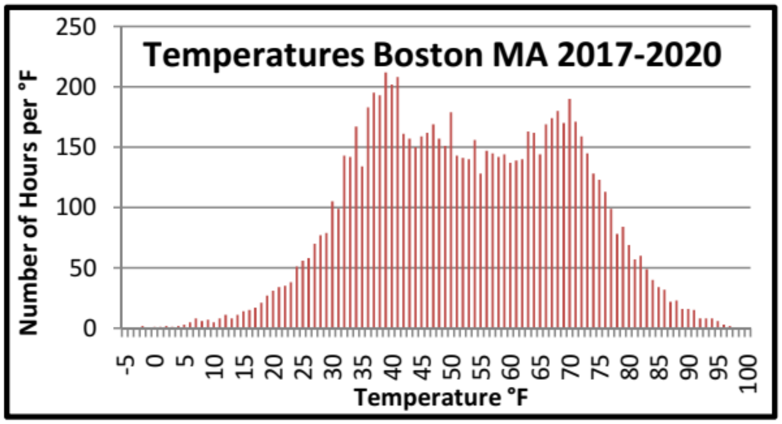


Figure 3.2: Histogram of Average Local Weather Data

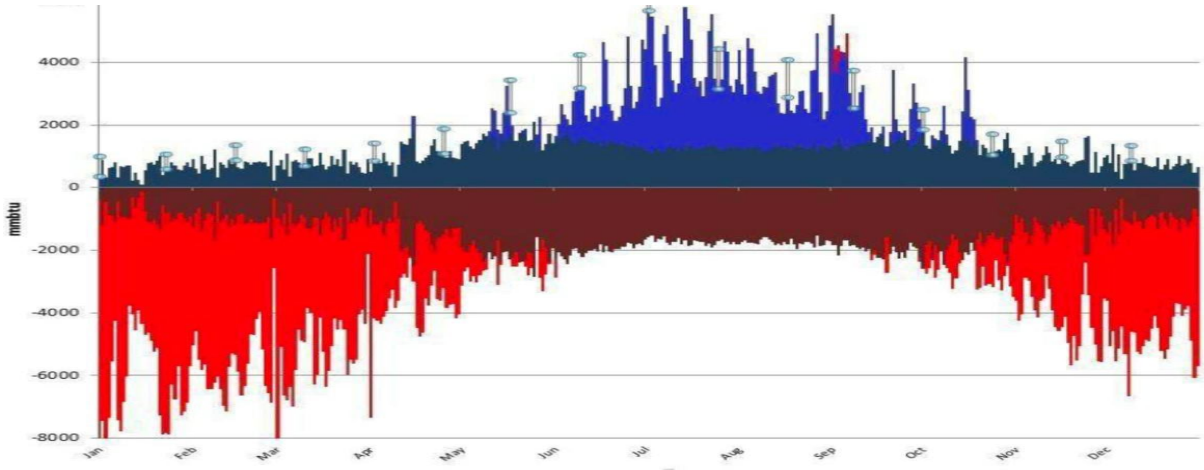


Figure 3.3: MIT campus Steam and Chilled Water loads for CW loop connected buildings[5]

Another key load of the existing central thermal plant is the loss in distributing steam and chilled water from the CUP to campus buildings. MIT's staff has said distribution losses are "just under 30%" for steam, and we expect ~10% for cooling. These are typical for 3rd Generation central plant district systems and will be fully eliminated with the proposed distributed heat pump ambient loop 6th Generation GDHC solution.

Another significant challenge at an urban campus like MIT is the need for low impact solutions. Many campuses have pursued 4th Generation GDHC campuses with very large central geothermal loop fields in free areas adjacent to those campuses[20]. MIT does not have such available free space.

The Design Paradigm: We propose implementing a highly cost-effective 6th Generation GDHC to fully eliminate carbon emissions from MIT's campus HVAC energy systems. As depicted in Figure 3.4 (next page) for one building with a full complement of the proposed elements, but intended for the entire campus on an "as needed" basis, this includes 6 key elements:
1) convert the existing Campus Chiller Loop thermal infrastructure into an Ambient Loop to distribute energy between buildings, 2) add Active Exhaust Energy Recovery to reduce or eliminate current building energy losses and to provide system coupled "hybrid" air exchange and/or Inclined Ground Heat Exchangers, 3) upgrade all HVAC Systems to distributed heat pumps, 4) add Ground Coupled Thermal Batteries at each building for lower-cost grid energy time shifting and optimal low-cost power utilization, 5) add Directional and/or Inclined Ground Heat Exchangers, and 6) add water utility thermal interfaces[21] and/or sewer energy recovery.[8]

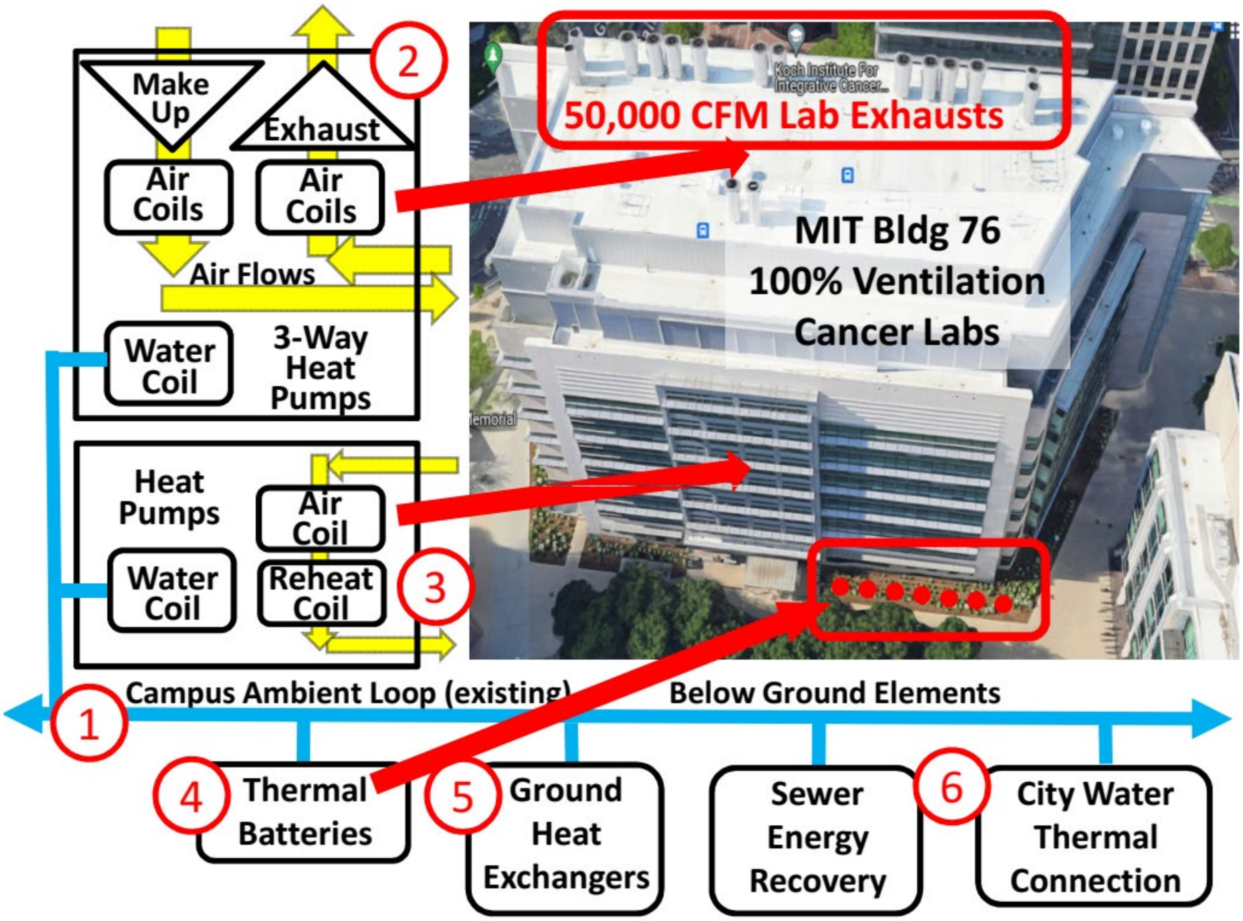


Figure 3.4: System Components shown with High Load Laboratory Building

We highlight these key 6th Generation Design features that allow us to reach our goals:

1) **Active Ambient Temperature Water Loop:** An “Ambient Loop” is a district fluid thermal loop operating with wide thermal limits (e.g., 45-90°F). MIT’s existing 45°F Chilled Water (CW) loop can be readily transitioned to this GDHC loop with a little attention to thermal pipe expansion (designed as CW only, may require mounting adjustments and expansion joint additions). All heat pumps added will have dedicated variable speed circulators and be connected to the Ambient Loop via “reversing” valves that enable one side of the loop to be warmer and the other colder, letting each heat pump select the thermally optimal inlet, improving overall efficiency and reducing central pumping requirements. This “active ambient loop” is a front edge idea to yield the most efficient thermal energy sharing possible. Even non-active Ambient Loops have been shown to reduce loop field sizes over 60%[9].

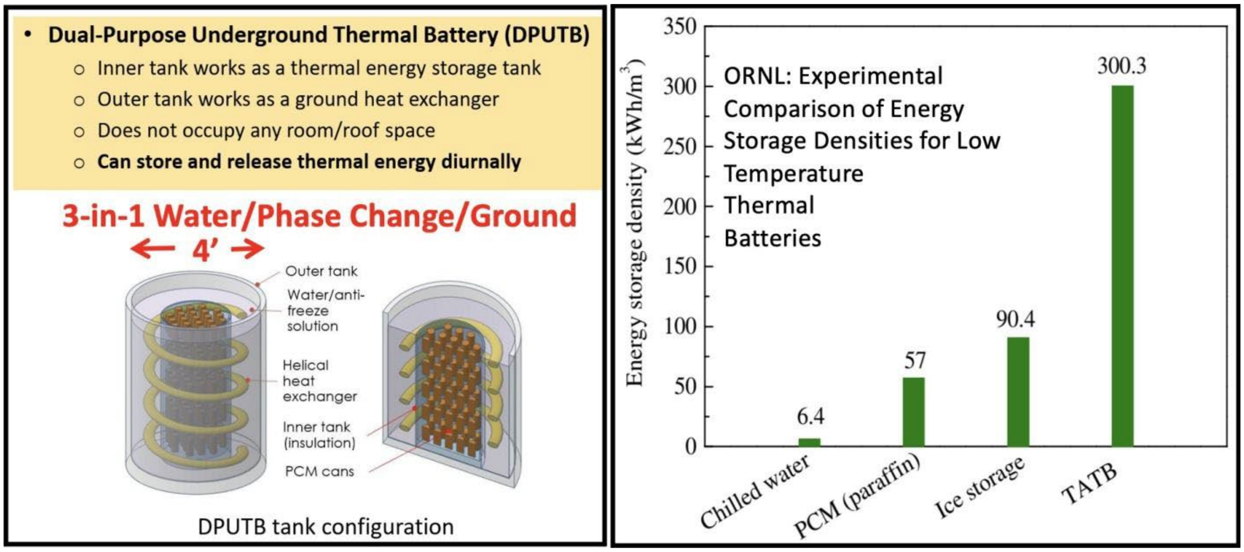
2) **Advanced Energy Recovery Ventilation:** With current HVAC loads likely being 50% due to exhaust losses, exhaust energy recovery is essential for cost-effective decarbonization. We propose Active Heat Pump driven energy recovery with Ambient Loop interconnection (3-way heat pumps). These heat pumps will achieve nearly 100% exhaust energy recovery except during the most extreme outdoor temperature conditions. Air velocities and equipment in the

lab exhaust systems have been analyzed and confirmed consistent with common air coils operating at the same air speeds, making them suitable to meet this need as a modular and easily retrofitted solution. Through the campus-wide Ambient Loop, Air Source Heat Pump (ASHP) “overdrive” thermal capabilities are also provided so all non-peak load situations can be utilized for Thermal Battery charging and GHEX seasonal tuning as needed when power costs are low.

3) **Building Heat Pumps with Reheat:** The same modular multi-way heat pump retrofit approach used for exhaust recovery will also be used throughout the campus to upgrade all existing cooling systems to Ambient Loop connected WSHPs for delivering both heating and cooling using existing HVAC ductwork. Included will be Reheat Coils for dehumidification and to enable low cost upgrade of existing “terminal reheat” systems with lower temperature heat pump supplied water. Perimeter wall conditioning will be added as needed.

4) **Thermal Energy Storage (TES):** Electric energy pricing will become increasingly volatile as clean energy becomes more dominant and the ability to utilize low-cost power will create a cost-effective HVAC system and help accelerate the Clean Energy grid to avoid curtailment. Regional ISO-NE grid costing data[2] shows there are already significant cost spikes both daily and periodically – a pattern that will be further exaggerated as the Clean Power grid expands as has already occurred in the western U.S. “Batteries” will be needed as part of the emerging Clean Energy grid to smooth out these power cost and availability fluctuations. Ground-coupled thermal batteries (Figure 3.5, [24]) are a novel thermal storage technology being actively tested by the Oak Ridge National Labs’ Thermal Energy Storage Research Group for this purpose. ORNL’s Thermal Batteries are an emerging ground heat exchanger technique combining ground coupling with tank storage and phase change materials (PCM) that release and absorb large amounts of energy when transitioned between liquid and solid. ORNL has uncovered thermal storage substances, such as the TATB shown in Figure 3.5, which stores over 47 times the energy as chilled water and 3.3 times as much as ice. These Thermal Batteries are a 6th generation technique allowing sites to rapidly store and use energy based on varying grid power cost.

5) **Novel Ground Loop/Thermal Battery Installation Techniques:** (see Geothermal Resource Assessment section above)



- **Dual-Purpose Underground Thermal Battery (DPUTB)**
  - Inner tank works as a thermal energy storage tank
  - Outer tank works as a ground heat exchanger
  - Does not occupy any room/roof space
  - **Can store and release thermal energy diurnally**

Figure 3.5: Thermal Battery developed by Oak Ridge National Lab (ORNL)

Conclusion:

MIT's energy loads are heavily affected by very significant exhaust waste energy made even worse by numerous labs that cannot use Energy Recovery Ventilation (ERV) desiccant wheels for contamination reasons. Our analysis, incorporating both building load data and exhaust system sensor data from a relatively modern lab (which is not the most inefficient on campus), indicates that approximately 50% of the current HVAC energy consumption is lost through exhaust. Eliminating this loss is a crucial first step for campus decarbonization. Advanced heat pump exhaust energy recovery is required to eliminate this waste.

Regional grid costing data shows significant cost spikes already occur daily and periodically–a pattern that will be further exaggerated as the Clean Power grid expands as has already occurred in the western U.S. Thus our proposed plan includes "Grid and Load Tuned" Ground-Coupled Thermal Batteries recently proven effective by Oak Ridge National Labs' (ORNL) Thermal Energy Storage Research Group, so the campus, which purchases power as an "Industrial" user on the spot market, can take full advantage of periods of lowest cost power to store excess thermal energy and avoid those periods of high-cost power.

MIT's fully saturated overburden soils are ideal for a reliable, low-cost, and lowest possible impact ground heat exchanger. The existing campus two-pipe CW loop can be easily transitioned to Ambient Loop GDHC and directional boring techniques can be used to avoid typical GDHC trenching operations. Thermal Batteries and directional bored GHEX can be readily installed in these soils. Our analysis shows there is plenty of GHEX space available in the overburden soils specifically because they are fully saturated. The Thermal Batteries benefit from the saturated soil's reliable thermal conductivity for additional capacity to store energy when grid power costs are low and use the energy to lower HVAC loads when grid power costs are high.

The proposed “Advanced District Heating and Cooling System” with Active Exhaust Energy Recovery & Thermal Storage will provide MIT with rapid and least-cost decarbonization. The plan includes:1) Recycle waste heat from all exhaust, especially high-volume lab exhaust;
2) Eliminate thermal transmission losses and minimize pumping loads; 3) Avoid need for a new campus distribution piping; 4) Recapture free energy from concurrent heating and cooling;
5) Enable maximal Clean Energy Grid Cost Optimization and accelerate overall transition to that Clean Energy Grid; and 6) Install all needed ground coupling with minimal disruption to MIT’s Campus.

The approach represents 6th Generation Decarbonized District Heating and Cooling, the most advanced available. Multiple Industry GDHC experts interviewed have concurred with the soundness of this plan and support the viability of the GHEX and Thermal Battery installation techniques presented.

We look forward to sharing our learnings with MIT’s decision-makers and staff. Furthermore, leadership opportunities exist in Thermal Battery and Grid Interactivity R&D for which MIT is well suited.

Next Steps: “Design” of a GDHC always requires full system “digital twin” modeling and experimentation with the various elements and their sizes. The modeling will be used to confirm the proposed design before committing to engineering and construction and for detailed costing analysis to meet financial targets. This next step is underway now at MIT through unfunded, class-related (D-Lab) and MACA alumni volunteer time.

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