ENVIRONMENTAL PERFORMANCE OF CAMPUS BUILDINGS - AN ENERGY SYSTEMS EVALUATION

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Introduction

- University campuses are significant consumers of energy and emitters of greenhouse gases.
- Many campuses in the USA have their own micro energy systems, centered around cogeneration plants.
- Cogeneration in local district energy systems often presumed to have greater efficiency and lower environmental impacts than alternatives such as separate heat and power production.
- This research critically examines that presumption, focusing on the current combined heating, cooling and power system at Yale University, and compares it with two feasible alternatives.

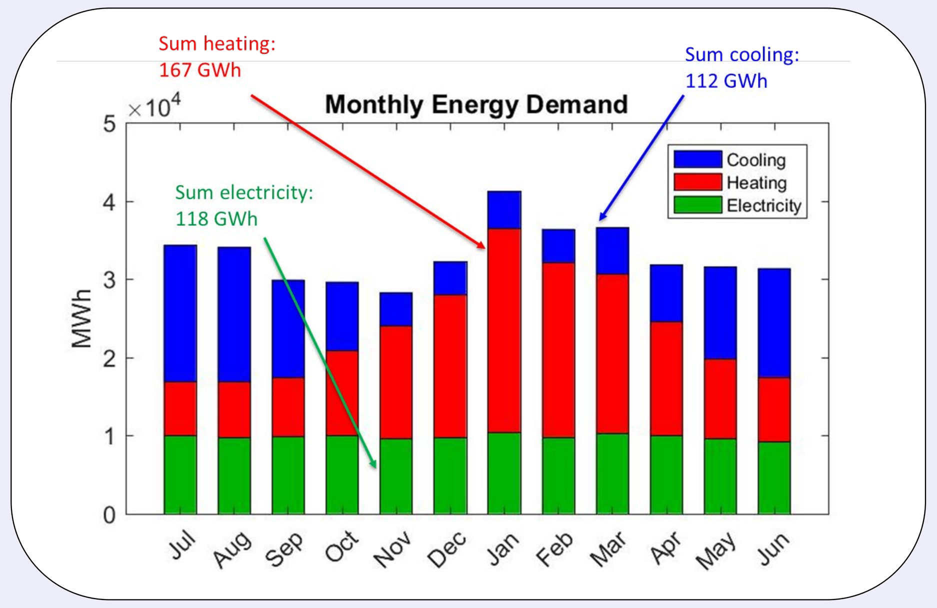
System Description

Three alternative energy supply systems are analyzed:

1) The current combined heat, cooling and power (CHCP) system consists of a gas fired cogeneration power plant with a heat recovery steam generator. A chiller plant, running on steam or electricity, produces chilled water.

2) A separate heat, cooling and power (SHCP) system would use ISO-NE electricity from the grid, produce chilled water solely from electrically powered chillers, and used gas directly in hot water boilers to meet the heating load.

3) A SHCP with heat recovery (SHCP-HR) system would use grid electricity, and produce chilled water and hot water as in system 2). Concurrent heating and cooling demands would be met by a heat recovery chiller (HRC) with thermal energy storage allowing the HRC to operate when the heating and cooling requirements are not well matched.



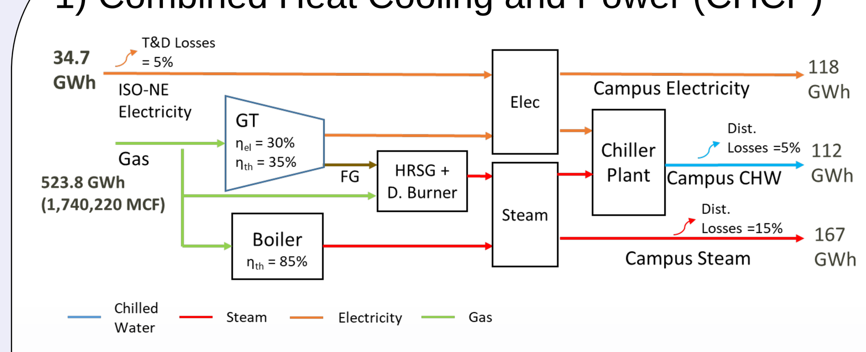
Heating and cooling loads vary with season. Concurrent heating and cooling loads in winter and summer are suitable for HRC thermal energy generation.

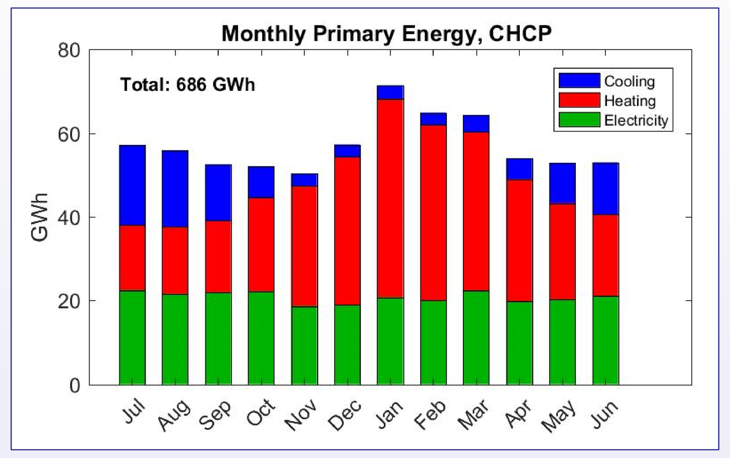
Methods & Data

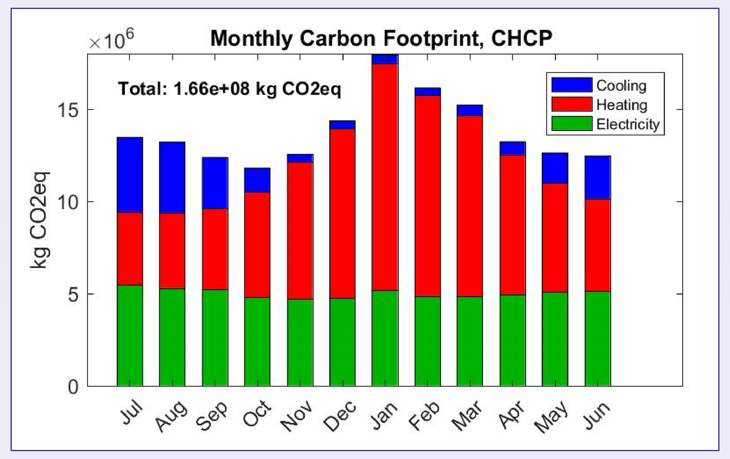
- THEMIS, a hybrid life cycle assessment model for analyzing electricity systems and scenarios, is modified to include the heating and cooling systems described.
- Grid electricity modeled as ISO-NE regional average: mainly natural gas (49%), nuclear (31%) and renewables (10%).
- Primary data from the Yale power plant is used for CHCP, the other alternatives are based on industrial literature and interviews.

System Comparison

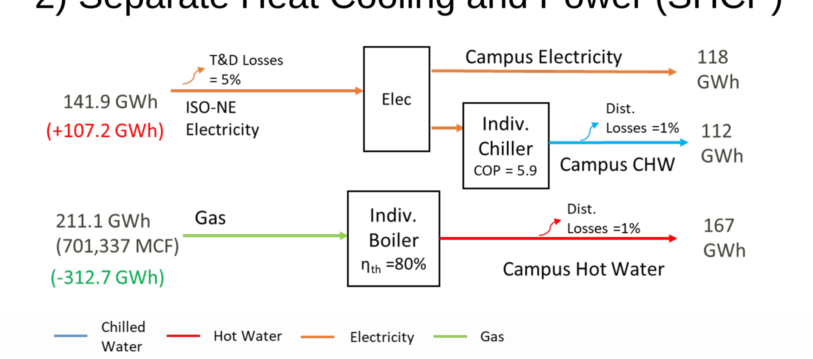
1) Combined Heat Cooling and Power (CHCP)

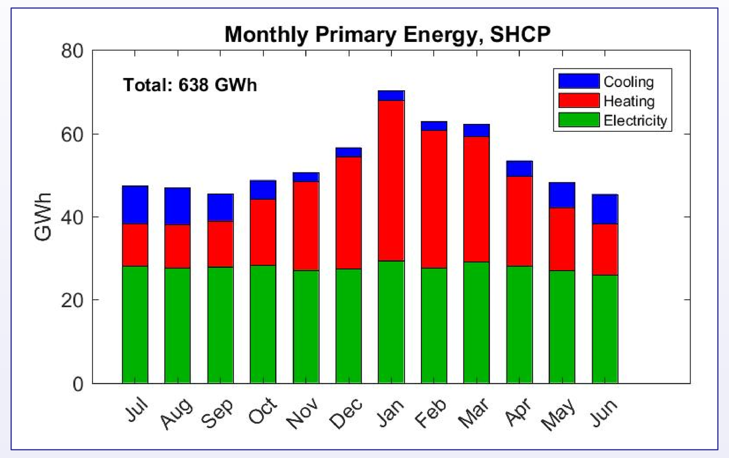


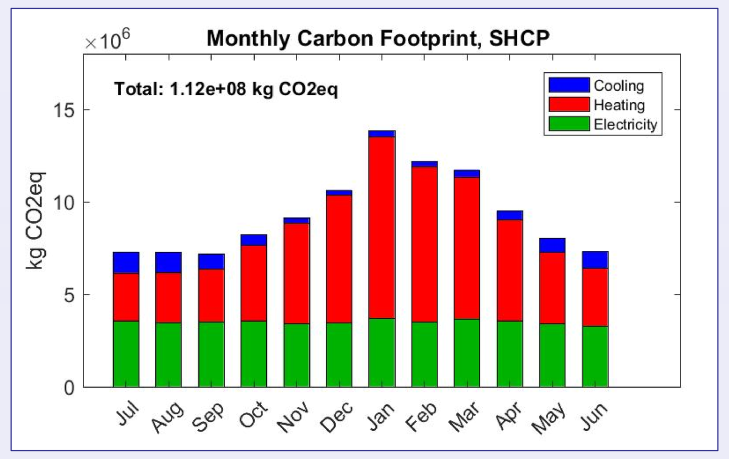




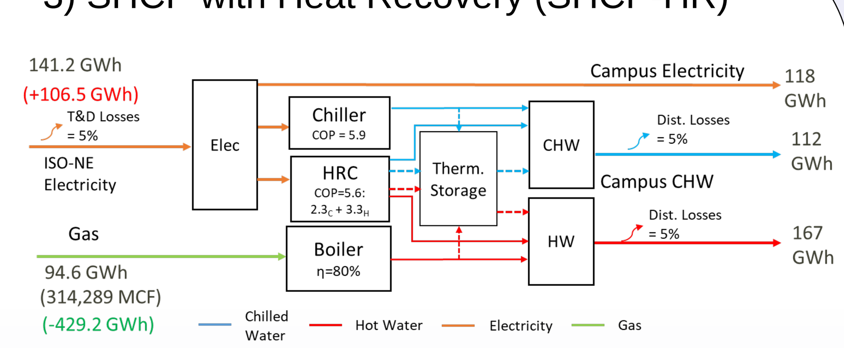
2) Separate Heat Cooling and Power (SHCP)

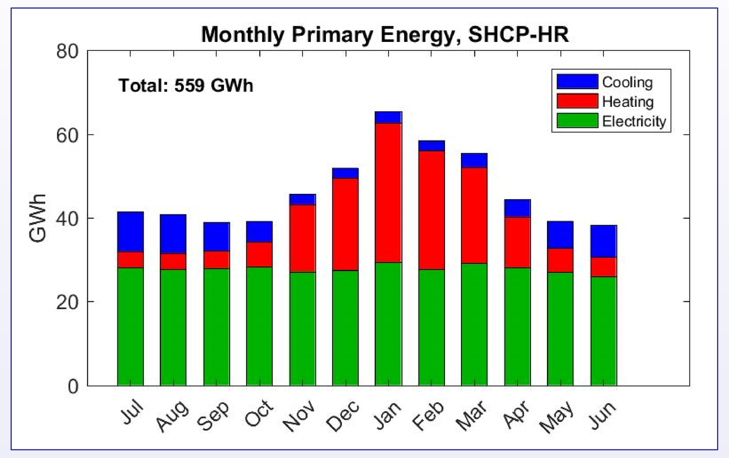


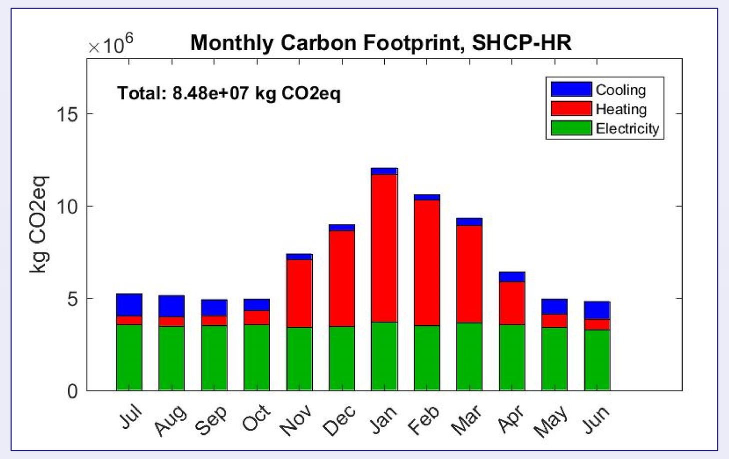


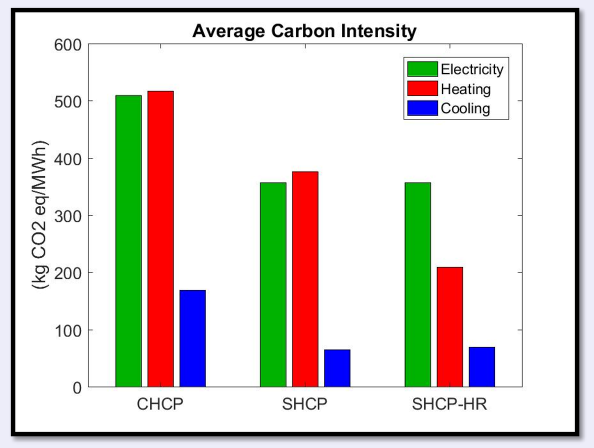


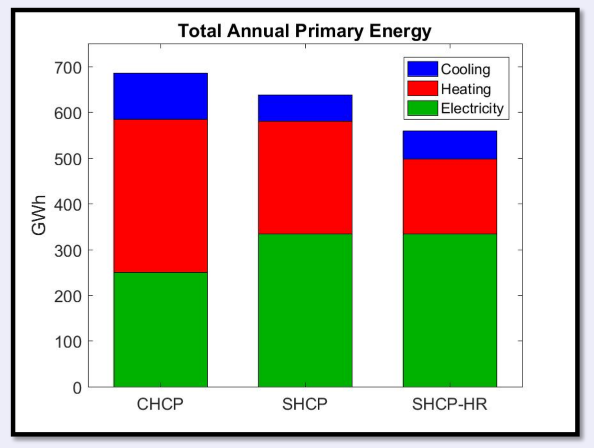
3) SHCP with Heat Recovery (SHCP-HR)

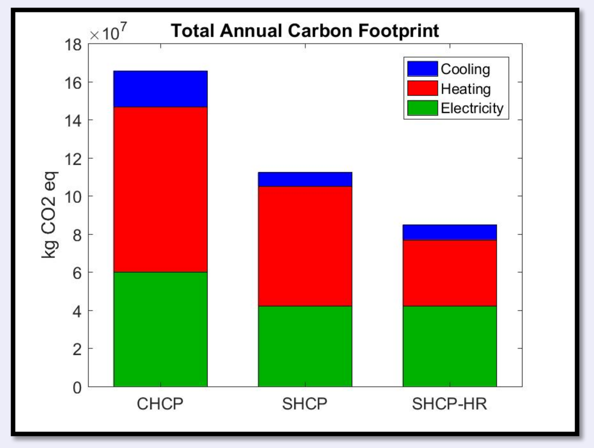












- Slight primary energy reductions and significant carbon footprint reductions are achievable in this case by switching to SCHP, more so with heat recovery (SHCP-HR).
- Reductions most pronounced in summer, when steam powered refrigeration can is replaced by electrically powered refrigeration (SCHP) and well matched heating and cooling loads allows most thermal energy generation to come from the HRC.
- Results are highly dependent on the regional electricity mix; because ISO-NE has a relatively low carbon electricity mix, the GHG reductions achieved by switching from CHCP are large.

Discussion

- Poorer performance of CHCP unintuitive, as we expect cogeneration to require less energy inputs and cause lower environmental impacts than separate generation.
- First of all, the relative efficiencies are crucial to this expectation. In decades past when average energy conversion by centralized power plants was 30-33% efficient, CHP would have been a better solution. Now however, as large scale generation becomes more efficient, CHP looks less favorable.
- Second, if reducing GHG is a priority and regional electricity mix contains low-C sources e.g. nuclear, renewables and high-efficiency natural gas, grid electricity and separate heating and cooling can be more favorable.
- Meeting concurrent heating and cooling loads with a HRC, with hot and cold thermal energy storage, can provide substantial further energy savings and environmental impact reductions.
- Short/long term resilience is a separate advantage of distributed, off-grid generation. Increasing on-site solar/wind power generation can improve resilience without the environmental downsides of CHCP.

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