UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Thermal Energy Demand Indices Targets for UBC non-DES Classroom/Office Archetype

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Executive Summary

Project overview

UBC has adopted high performance standards for new construction with an approximate 25% improvement beyond ASHRAE 90.1-2010. Further to this, UBC has set ambitious GHG reduction strategies, including a target of achieving a net positive campus ("zero" emissions) by 2050. Corresponding to UBC university-wide net-zero emission strategy, many programs addressing emissions reduction have been initiated, developed, and managed to eradicate Greenhouse Gasses (GHG) emission. This project is categorized to be one of them, aiming at thermal energy demand and related GHG emissions of one on campus archetype – Classroom/Office – which would help understand the emission difference among different thermal energy supply systems, financially and scientifically. Additionally, this project would attempt to close the emission gap between systems by rearranging the implementation date of energy conservation measures.

Firstly, this project interprets what the previous RDH consulting report has studied into energy consumption and investigated the integral unenforceable energy use that can be reduced. Energy consumption has been categorized into 6 segments (Pumps & Fans, Domestic Hot water, Heating, Cooling, Lighting, and Miscellaneous Electricity), and two of them, thermal energy supplies, have bee considered as the priority of this project.

Secondly, since the thermal energy demand of these two categories decrease each time when new measures were simulated, distinct thermal demand can be determined. Thermal energy demand directly determines how much energy can a heating system consume as well as reflects GHG emissions. In other words, different thermal supply systems can only be simulated to investigate their financial and environmental cost based on their valid thermal energy consumption.

Thirdly, it was pragmatically challenging to request for accurate quotations when it came to determine cost of different thermal supply system without a professional procurement team. Therefore, it was suggested that estimation of the cost would be viable, and the industrial estimation tool, RSMeans, deployed in this project was one of the leading estimation platform in the world. It consists factors of location, contractors, and overhead and profit of vendors, etc. Although the engineering estimation tool was quite powerful, this study compiled all the calculations based on the 2014 master form, which could be a problem of inaccuracy in terms of capital cost of infrastructures.

Fourthly, environmental impacts are as well critical to UBC's success in accomplishing the Net-Zero emission strategy, except for financial implications of the three thermal supply systems. This study simulated GHG emissions of systems by applying emission factors developed by BC Minister of Environment. It also compared the GHG emissions and determined how large are the gaps between heating options.

Finally, it attempts to close the gap by re-engineering the ECM's adopted in the energy model provided by the RDH report. Although it was quite a challenging methodology to determine the effect of combination of ECM's, this study calculated thermal energy demand with data provided by project sponsors and the previous report. Therefore, some nuance between the real-world thermal demand and the simulated results can be allowed, and they are beyond the scope of this project.

Key findings

The energy consumption has been simulated as four basic conditions indicating incrementally different ECM bundles. Figure 1 (Appendix B) shows the energy consumption of the District Energy System (DES) option in 2015, 2020, 2025, and 2030. It was not hard to notice that thermal energy demand has been decreasing throughout the period between 2015 and 2030 due to highly efficient ECMs have been simulated in the model.

Energy Use Intensity (EUI)

- The EUIs of DES heating system have been dropping from 114 kwh/m^2 in 2015 to 67 kwh/m^2 in 2030, by 42%.
- The EUIs of Natural Gas Heating (NGH) heating system are 120.1, 85.5, 73.5, and 67 kwh/m^2 in 2015, 2020, 2025, and 2030.
- The EUIs of Electrical Boiler Heating (EBH) heating system are drastically similar to DES system.

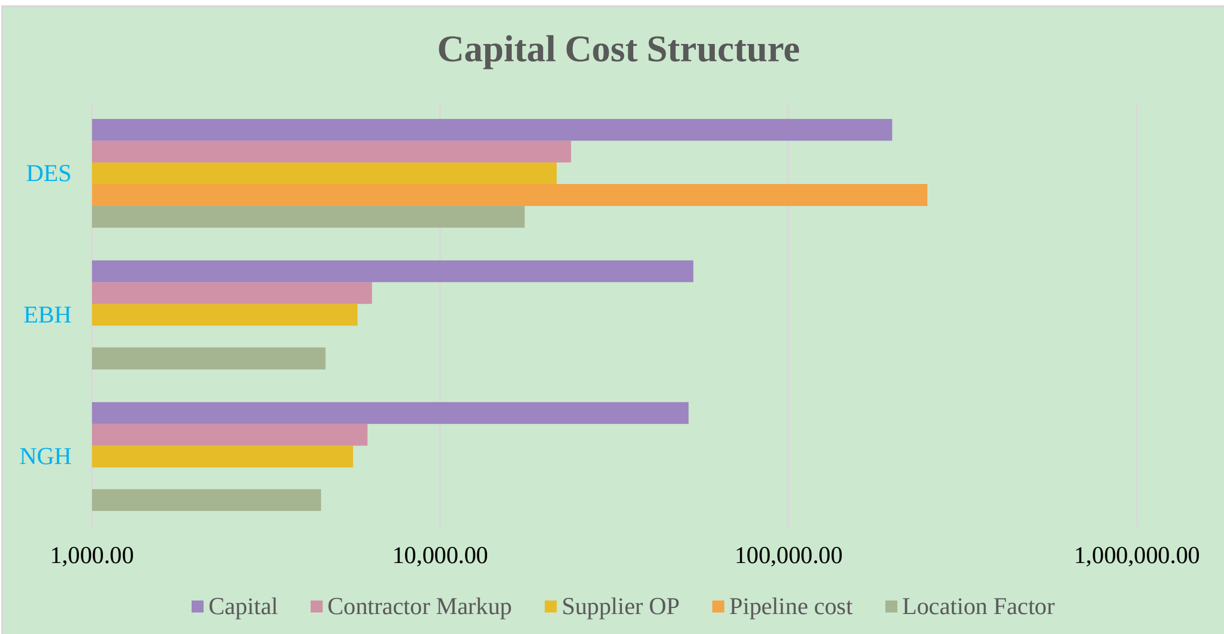
Thermal Energy Demand Indices

Thermal energy demand of three options have been revealed below and it was suggested that NGH is the most demanding option among them. It was not hard to notice that thermal energy has been significantly decreased as the ECM bundles evolve. Additionally, NGH is the highest in terms of thermal energy consumption, although ECM's reduced the consumption.

TEDI of three thermal energy supply systems

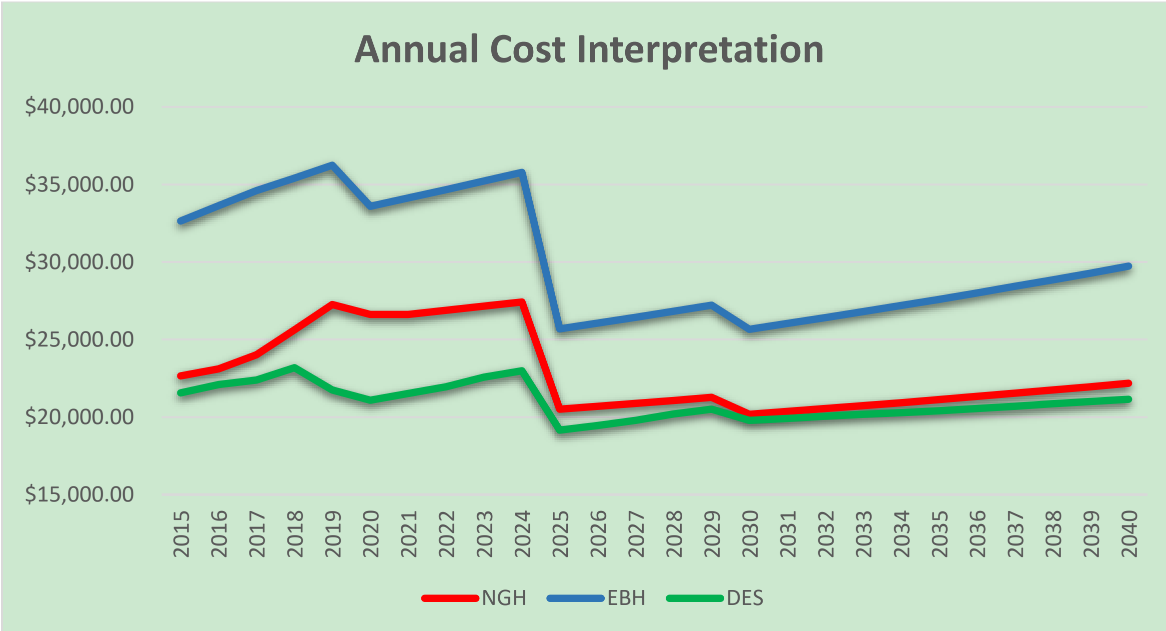
Cost Interpretations

The cost of three thermal energy supply systems are shown below, it is not hard to notice that the DES costs more than its counterparts do. It was anticipated that the cost of DES can be fairly high considering the scale of its manufacturing and installation. However, the equipment of DES is remarkably longer-living compared other heating options. For instance, the equipment used for DES, NGH, and EBH can last approximately 40, 25, and 10 years, respectively.



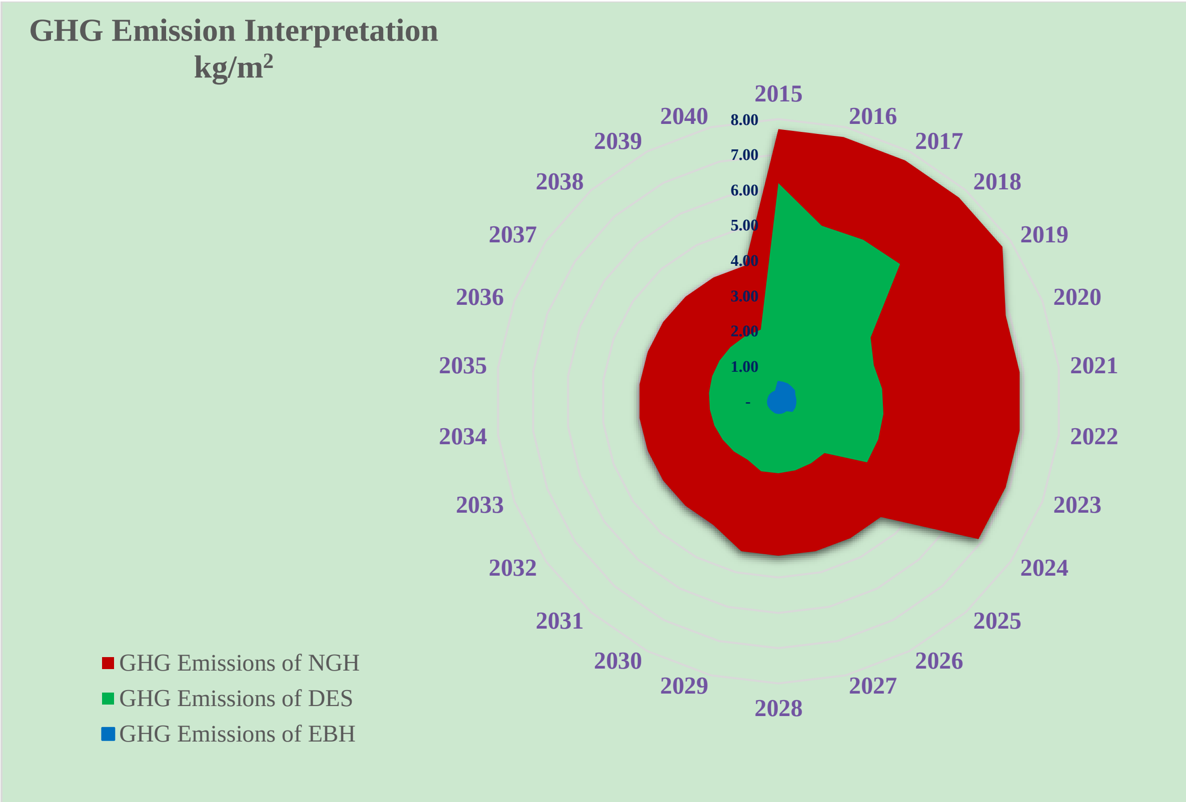
The structure of capital cost

Predicted annual total cost of three systems are presented below. EBH imposes the highest cost, as high as $37,000 a year, and DES imposes the lowest cost, as cheap as $17,000 per year. As we can see, significant cost reductions happen at 2025, where most efficient ECM's were adopted. So no matter if the goal is cutting cost or reducing emissions, energy consumption reduction is one critical path to attain the mission.

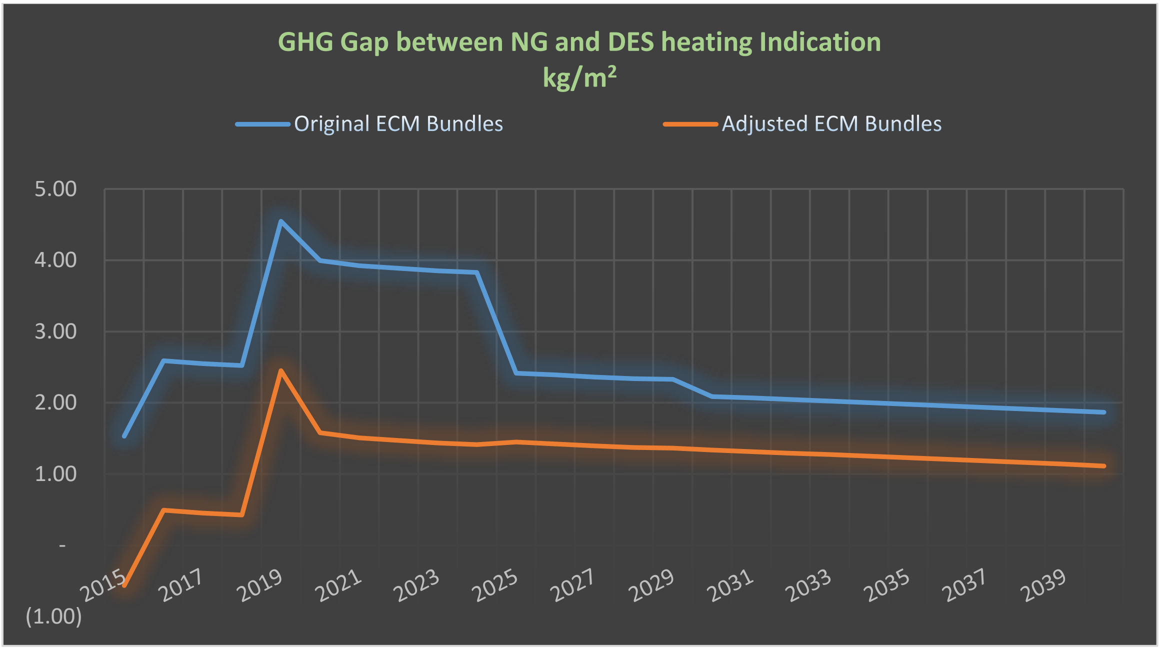


GHG emissions

Greenhouse Gasses emissions have been calculated as a function of emission factors provided by the local government (the Minister of environment BC). The GHG emissions of the three options can be found below.



The GHG emission gap between NGH and DES can be narrowed down to a minimum by rearranging and integrating more ECM's. The figure below shows how small can the emission difference be. Perceptively reflected by thermal energy demand indices, it can deduce the TEDI tier targets for classroom/office not connected to DES.



TEDI Targets

To achieve similar level of GHG emissions, Classroom/Office building with NGH option should at least achieve TEDI at 31.39, 24.93, 19.05, and 17.92 Kwh/m2 in 2015, 2020, 2025, and 2030.

Table of Contents

Research Question

UBC's RDH Net Zero Modelling study provided EUI (Energy Use Intensity) recommendations for classroom and offices connected to the UBC District Energy System (DES) for 2015, 2020, 2025, and 2030.

Further to that UBC has adopted high performance standards for new buildings with an approximate 25% beyond ASHRAE 90.1-2010 standard, the university also has set ambitious GHG reduction goals, including a target of achieving a net positive campus by 2050. Based on the recent Net Positive Modelling Study by RDH, this specific project is attempting to decide the TEDI targets for a particular category of archetype that is Classroom/Office not connected to UBC's DES, in order to assess if the similar level of GHG emissions to DES can be attained. If yes, how close can emissions to both system be.

Project Benefits

By studying the TEDI tiers for different thermal energy supply systems, the university would possess a guideline for new buildings not connected to DES. In other words, this study would be providing arguments to ensure that any new buildings are planned to cooperate with the university-wide new-positive emission strategy by adopting the best heating option in terms of energy consumption and GHG emissions reduction.

Project Scope

As discussed with project sponsors, based the timeline and workload determined, the project scope has been defined as the following:

1. Determine the TEDI targets of Archetype 5 that is Office/Classroom not connected to DES, for 2015, 2020, 2025, and 2030;

2. From the TEDI's, determine the greenhouse gas emissions for the Classroom/Office archetypes by applying a GHG emissions factor based on a de-carbonization of the DES system over time (supplied by UBC EWS);
3. Reverse engineering what the EUI targets would be for buildings not connected to DES;
4. Translate this EUI target to GHG target using BC's GHG emission intensity for natural gas;
5. Discuss the gap in GHG emissions between DES connected and non-DES connected buildings. Provide recommendations for closing this gap and for further studies.

Methodology

Energy Modelling

It is generally reasonable to assume that the newly built classroom/office buildings are going to consume energy resembling the pattern as the model built in the previous study. Since Energy Conservation Measures (ECMs) are going to be deployed in 2015, 2020, 2025, and 2030 based on their positive NPV values of bundles (evaluated and selected by industrial and academic experts in the previous study), the model studied in this project is going to adopt the identical bundles of ECM's as baseline model at the same time as DES connected counterparts. Energy consumptions have been categorized into Hot Water Supply, Conditioned Space Heating, Cooling, Lighting, Miscellaneous Electricity, and Fans and Pumps. This project mainly focuses on the thermal energy consumption due to the nature of academic question.

This 4-storey, 9,300 m^2 (100,000 ft^2) baseline academic building is based loosely on the plans for Buchanan A, B, and C blocks. The occupancy space includes classroom and lecture hall (46%), office (20%), and circulation/amenity space. The building enclosure consists of concrete construction with steel stud walls and aluminum frame windows. The baseline building has Variable Air Volume (VAV) ventilation with DX cooling and is not connected to district heating. Under this condition, the energy model should consume less and less as more ECM's will be implemented; however, this project would provide more thermal energy supply systems to replace the current DES option to see the thermal energy demand and GHG emission differences. Therefore, the past energy model remains the same in this study before the adjustment of ECM bundles.

Parameters of Efficiencies

Heat Exchangers are hypothetically 97% efficient in the DES system (pipeline heat loss considered); however, HEs of the targeted individual heating system will be 97% efficient since there will be little pipeline heat loss.

Conventional natural gas-fired boilers exhaust flue gas direct to the atmosphere at 150–200 Celsius, which, at such temperatures, contains large amount of energy and results in relatively low thermal efficiency ranging from 70% to 85%. So, NG boilers are considered as 83.3 % efficient along with its capital cost in this study. On the other hand, Electric boilers are considered 99% efficient out of its high exergy and high energy quality prosperity.

Additionally, this study excludes pipeline thermal energy loss as it is beyond the scope of this project. So the efficiency of pipeline here was presumed to be 100%.

Energy Conservation Measures

The individual ECMs were combined into bundles aiming at saving energy, and their mission is to lead to the optimized savings in terms of energy and money by 2040. Bundles were selected based on the evaluation results of each individual ECM (total NPV greater than zero), market readiness, and the appropriateness of whole building design. While some of the enclosure measures had negative NPVs when simulated individually, better savings are only captured when they are bundled with other performance measures, and therefore have been included in bundles. ***Table 2*** (Appendix A) shows what ECMs were integrated at a specific point of time.

Thermal Energy and Progression

Based on the ECM constraints, energy consumption can be determined for three energy supply systems. Energy consumption is based on historical and predicted energy consumption data from the actual academic building Buchanan blocks. ***Figure 1*** a, b, c, and d (Appendix B) show energy consumption for DES option in 2015, 2020, 2025, and 2030, respectively, as a result of the implementation of original ECM bundles. It is notable that overall EUIs have been decreasing over time from 114 Kwh/m^2 to 67 Kwh/m^2, by 42% in these years. Additionally, thermal energy demand also shows a decrease.

However, if the building adopts condensing natural gas boilers as heating source, it would consume more thermal energy as ***Figure 2*** (Appendix B) shows. Although natural gas boilers are popular in the market and explicitly cheap to many building developers, it still consumes more energy than other options.

Cost Analysis

Assumptions of cost calculation laid out are practical. Firstly, the capital cost data was provided by the RSMeans[1] engineering tools for construction cost. It has been industrially recognized by many construction companies and was recommended by the UBC Energy and Water Service. Please investigate ***Table 3*** for details of assumptions and parameters that were either chosen or interpolated from RSMeans Handbook.

This project estimated total cost of natural gas boiler heating and to electric boiler heating, compared to DES heating. Based on different cost structures, thermal energy demand indexes are

1 RSMeans is the world's leading provider of construction cost data, software, and services for all phases of the construction lifecycle. https://www.rsmeans.com/

therefore different. However, we considered the same foreground and background boundaries just so the comparison can be consistent and reliable.

Utility rates were provided as real time rates and considered a 2% annual growth. Please refer to ***Table 4*** a. b., and c. (**Appendix A**) for rates details.

GHG Emissions

Emission factors are expressed in kilograms (kg) or metric tons (t) of GHG emissions per unit of consumption activity. Typically, the factors for a given category of activity – for example, building energy or fleet fuel consumption – are expressed in common units to enable comparison across different fuel types, travel modes, etc. GHG emission factors for electricity and natural gas are based on the data provided by BC Ministry of Environment.[2]

- 2.78 Kg GHG emissions per GJ Electricity
- 49.75 Kg GHG emissions per GJ NG

GHG emission factors for DES system are collected and projected by the Energy and Water Service UBC, which are dynamic for each year. Please see **Table 1** (Appendix A) for detailed information of DES GHG emission factors[3]. To calculate the normalized emissions of each heating option, this study considered the measured energy consumption and the emission factors.

$$Emissions = Factor\left(\frac{kg}{GJ}\right) \times energy\ consumption\left(\frac{GJ}{m^2}\right)$$

2 BC Ministry of Environment. 2014 B.C. Best Practices Methodology for Quantifying Greenhouse Gas Emissions. http://www2.gov.bc.ca/assets/gov/environment/climate-change/policy-legislation-and-responses/carbon-neutral-government/measure-page/2016-2017_bc_best_practices_methodology_for_quantifying_ghg_emissions.pdf

3 Email correspondence from Energy and Water Service UBC

Closing the GHG emissions gap

As predicted, there will be an emission gap between NGH and DES, but it is better to be narrowed. the method here in this project is rearranging ECMs to meet energy consumption reductions so that GHG emissions can be reduced. For example, the implementation of highly efficient ECM in 2030 can be adopted earlier into 2015 in order to reduce energy consumption and therefore emissions. So this study rearranged and added available ECMs based on their performance of consumption reduction. (***Figure 3.*** Appendix B)

Results and Discussion

Financial Cost

Financial incentives appear to be essentially important when it comes to decision making for a architect, and the disclosure of all related cost of each heating option is as well critical here in this study. So, fixed and variable cost of each heating systems were determined in order to compare them so that the best option can be recommended.

Capital Cost

As we can see the capital cost has been investigated and shown in ***Figure 4.*** (Appendix B)

Capital cost of NGH appears to be lower than the costs of DES and EBH, which makes it financially attractive to many investors when it comes to approve heating system design of a building. Although whether it is environmentally shortsighted to select NGH is beyond the point of designing a building, NGH does appear to be financially attractive if the budget is not a flexible constraint at all. NGH option was estimated to be $68,000.00 for the overnight cost compared to the overwhelming cost of DES, $465,968.00.

EBH option costs generally more than $70,000 as capital investment, and industrial electric boilers are getting cheaper and cheaper in the market, though.

As we can see that the capital cost of DES is fairly large, compared to other heating options. Although DES heat exchangers comparatively cost more than equipment used for other heating options, they are not the main cause for DES to impose the expensive capital investment. Instead, the DES pipeline cost does impose the highest infrastructure cost. The pipeline cost was estimated to be $2,500 per meter, and the average distance of connection is over 100 meters. So, it would be interesting to consider the cost infrastructure of DES and attempt to decrease it, especially for DES pipelines.

Total Cost

Total cost of each option has been signified in ***Figure 5***. (Appendix B)

Based on the life-span of different equipment, the dynamic annual cost of each heating option proves that the DES option is the winner. It cost 35% less than EBH and nearly 15% less than NGH. The cost difference between DES and NGH and that between DES and EBH can be seen in ***Figure 6.*** (Appendix B) Overall in 25 years, DES can save over $49,000 and $237,008 compared to NGH and EBH, respectively.

GHG emissions

GHG emissions reduction is one of the priorities that the university has been concerned over the years. Architects are decidedly concerned with emissions of buildings, so investigation of the GHG emissions became one goal of this project. Different heating options discharge GHG different amount. (***Figure 6.*** Appendix B) To start with, NGH imposes the highest GHG emissions, nearly 8 kg GHG equivalent emissions per meter square floor area in 2015, and less than 4 kg/m^2. As ECM's have been implemented, GHG emissions were reduced as energy consumption was reduced. Besides, DES emits 6 kg/m^2 in 2015 and plummets to less than 2 kg in 2040. Although it is a better option compared to

NGH, it constructs much on campus and concrete makes emissions as well. EWS UBC provided emission factors that considered its operation of DES so that emissions can be determined more accurately. Finally, the EBH option imposes less than 1 kg/m^2 and looks the best option. The reason why it emits significantly less than other options is that the electricity we consume here in BC Canada is mostly produced by hydro power, which is one type of renewable energy source; therefore, it has the lowest emission factor.

Closing GHG gap between DES and NGH

Before the adjustment of ECM's, TEDI of three options (***Figure 7*** Appendix B) are similar to each other, and they are not enough for interpreting GHG emissions tier targets. Due to the intention and university-wide emission reduction strategy, it is not recommended that electric boilers can be deployed as the heating supply source, although they are ideal in terms of less GHG emissions. Plus, EBH option costs so much (approximately 125 thousand dollars more than DES in its life-cycle) every year that the overall building cash flow might be too low for other building operations, annually. Therefore, NGH and DES are to be discussed, if similar GHG emissions of both option can be achieved by rearranging ECM's built in the energy model.

After rearranging and adjusting ECMs, the closest GHG gap can be achieved as ***Figure 8*** (Appendix B) Shows. The largest GHG emission gap and the smallest gap between NGH and DES were 4.55 kg/m^2 in 2019 and 1.55 kg/m^2 in 2015 before ECM bundle adjustment. After the improvement suggested in the methodology, the GHG gap has been reduced 60% averagely. In other words, NGH can emit 23 kg/m^2 less or 230 tons less GHG (in the case of a floor area of 9300 m^2) in a life-cycle of 20 years.

Conclusion and Study Recommendation

In conclusion, similar GHG emission level can be achieved if new buildings are not connected to DES, identical GHG emissions is not possible if energy demand remains, though. The study shows that TEDI targets for Classroom/Office archetype using NGH should technically be set at 31.39, 24.93, 19.05, and 17.92 Kwh/m^2 in 2015, 2020, 2025, and 2030, respectively, if a similar GHG emission level of DES is desired. Adopting energy conservation measures sooner can improve energy efficiency, achieve emission reduction goals set by the university, and promote the concept of energy conservation. Additionally, since the DES option appears to be financially sustainable and environmentally attractive based on the analyses done in this study; therefore, it is the best heating option for this archetype.

Although the approach of adjusting ECM's is feasible, recommendation for future study is necessary. Firstly, the capital cost of DES should be reduced, especially the cost of pipeline connection. Since energy conservation weighs much in the development of modern commercial buildings, it is an intoxicating idea to adopt DES in wider communities and have the heating supplied centrally. However, the capital investment remains comparatively high and repels building developers. So, a study on the pipeline cost in terms of manufacturing, installation and maintenance can help reduce the cost of pipelines so that it can be more viable to the public. Alternatively, the university or any other organizations that want to adopt DES can also adopt economies of scale by communicating with other building developers to increase the demand of equipment used for DES so that the cost of manufacturing special pipelines can be reduced. On top of that, making DES mandatory in a community wouldn't be the worse idea at all because of its excellent performance in terms of financial and environmental profit. Secondly, it must include clean energy source to produce extra energy in order to achieve net-positive emission goal. As we noticed that as long as there is consumption of primary fuel, there will be emissions, even in BC where electricity is generated by hydro power. The feasible way to achieve UBC net-positive goal is to produce electricity by clean energy source so that the overall emission can reach “zero” target. Thereby, a project that builds different widgets of clean energy source to reach a “break-even” point where the negative emissions of energy produced equates that of energy consumed can be meaningful. Thirdly, behaviors of occupants can have significant impact on GHG emissions. Since the targeted archetype has certain psychographic type of occupants, it is very interesting to do a study on the GHG impact of behavioral changes and a project that attempts to recommend or propose behavioral change strategies.

Acknowledgement

This project was initiated and strongly supported by ***Penny Martyn***, Green Building Manager, Project Sponsor, Campus and Community Planning UBC. who provided insight and expertise that greatly inspired me along the progression of this project.

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I would like to express my greatest thanks of gratitude to my course instructor, a knowledgeable friend, and true master of mentorship, ***Dr. Vladan Prodanovic***, Director of Clean Energy Engineering program, as well as the principal project coordinator, ***Ms. Hannah Brash***, UBC SEEDS, who gave me the golden opportunity to participate and work on this wonderful project on the topic of Building energy conservation and GHG emissions, which also helped me in doing a lot research and I came to know about so many interesting and new things.

Appendix A Tables

GHG Emission Factor	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
DES (Kg/GJ)	46.44	38.50	38.80	39.00	23.80	24.30	24.90	25.20	25.50	25.70	26.00	26.30	26.70
GHG Emission Factor	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
DES (Kg/GJ)	27.00	27.10	27.40	27.71	28.02	28.33	28.65	28.97	29.30	29.63	29.96	30.30	30.64

Table 1 *GHG emission factors for DES (Kg/GJ)*

Table 2 SUMMARY OF ECMS IN EACH PACKAGE

2015	**2020**
• Windows U-0.4 • LPDs 25% below ASHRAE 90.1-2010 • Occupancy sensors • Daylight sensors • Demand controlled ventilation • Low flow fixtures	2015 Bundle + • Walls R20 • Windows U-0.28 • Airtightness (USACE Target) • Reduce office plug loads • Natural ventilation • Radiant heating/cooling
2025	**2030**
2020 Bundle+ • Windows U-0.17 • Airtightness – Passive House	2025 Bundle+ • Walls R25 • Roof R40 • Fixed exterior shading

Table 3 ASSUMPTIONS AND PARAMETERS FOR COST ANALYSIS

Electric Boilers:

- Sized to 125% of peak heating load
- Power: 1400 MBH
- Quantity: 2
- Unit Cost: $ 26620.24
- Life-span: 10 years

DES Heat Exchangers:

- Sized to 125% of the peak heating load
- Flow: 1100 GPM
- Quantity: 2
- Unit Cost: $ 99250.00
- Pipeline cost: $2500/meter
- Life-span: 40 years

Natural Gas Boilers:

- Sized to 125% of the peak heating load
- Power: 1400 MBH
- Quantity: 2
- Unit Cost: $ 25825.49
- Life-span: 20 years

General Parameters*:*

- Service Charge of DES includes installation and maintenance.
- Maintenance for NGH includes certificate charge and labor cost: 6.25% of $35/hour per week. ($4550/year)
- Location factor of equipment: 108.8% (Vancouver, BC Canada)
- Contractor Markup and subcontract: 10%
- Contractor Overhead and Profit: 10%

Year		**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Electrical Charge	$/kWh	0.0637	0.0662	0.0686	0.0706	0.0727	0.0742	0.0756	0.0771	0.0787	0.0803	0.0819	0.0835	0.0852
Carbon Offset	$/kWh	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Total	$/kWh	0.0640	0.0665	0.0689	0.0709	0.0730	0.0744	0.0759	0.0774	0.0789	0.0805	0.0821	0.0838	0.0854
Year		**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Electrical Charge	$/kWh	0.0869	0.0886	0.0904	0.0922	0.0940	0.0959	0.0978	0.0998	0.1018	0.1038	0.1059	0.1080	0.1102
Carbon Offset	$/kWh	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Total	$/kWh	0.0871	0.0889	0.0906	0.0925	0.0943	0.0962	0.0981	0.1001	0.1020	0.1041	0.1062	0.1083	0.1104

Table 4 *a. Electricity Rates*

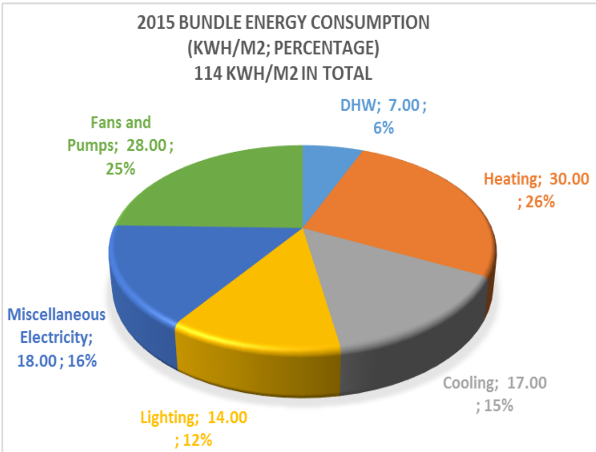
Natural Gas	Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Rate 25 Gas Rate	$/GJ	$7.46	$7.77	$8.40	$9.02	$9.65	$10.28	$10.49	$10.70	$10.91	$11.13	$11.35	$11.58	$11.81
Carbon Tax /GJ	$/GJ	$1.49	$1.49	$1.49	$1.99	$2.49	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99
Carbon Offset /GJ	$/GJ	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24
Total	$/GJ	$10.19	$10.50	$11.13	$12.25	$13.38	$14.51	$14.51	$14.71	$14.92	$15.13	$15.35	$15.57	$15.80
	Year	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Rate 25 Gas Rate	$/GJ	$12.04	$12.29	$12.53	$12.78	$13.04	$13.30	$13.56	$13.84	$14.11	$14.39	$14.68	$14.98	$15.28
Carbon Tax /GJ	$/GJ	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99
Carbon Offset /GJ	$/GJ	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24	$1.24
Total	$/GJ	$16.03	$16.27	$16.51	$16.76	$17.01	$17.26	$17.52	$17.79	$18.06	$18.34	$18.62	$18.91	$19.20

***Table 4** b. Natural Gas Rates*

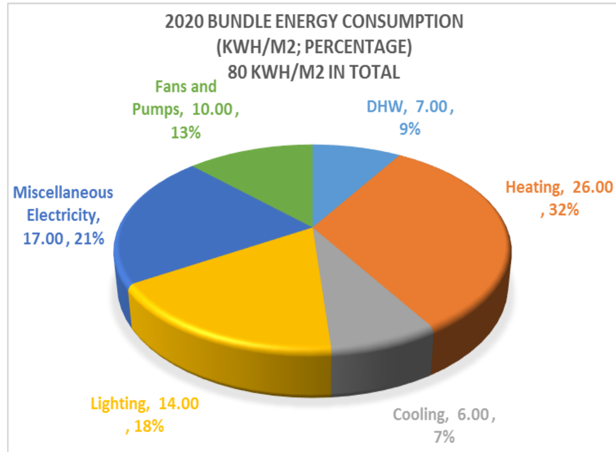
DES		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
	$/GJ	$8.00	$8.43	$8.67	$9.31	$8.15	$8.53	$8.94	$9.33	$9.89	$10.26	$10.68	$11.12	$11.56
		2028	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
	$/GJ	$12.18	$12.59	$12.78	$12.99	$13.20	$13.42	$13.56	$13.78	$14.00	$14.24	$14.47	$14.71	$14.95

***Table 4** c. DES Thermal energy charge*

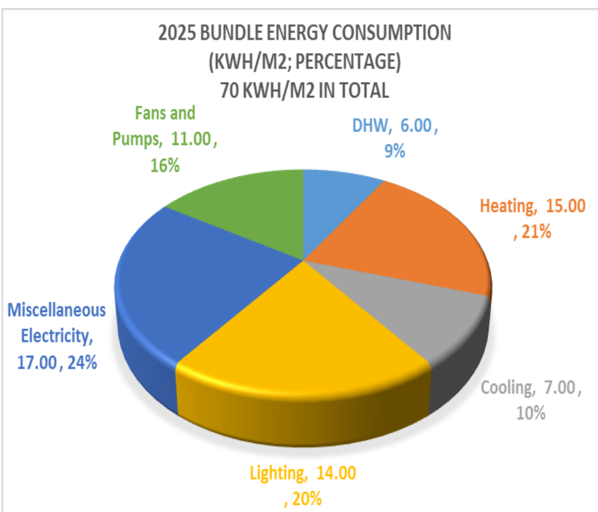
Appendix B Figures



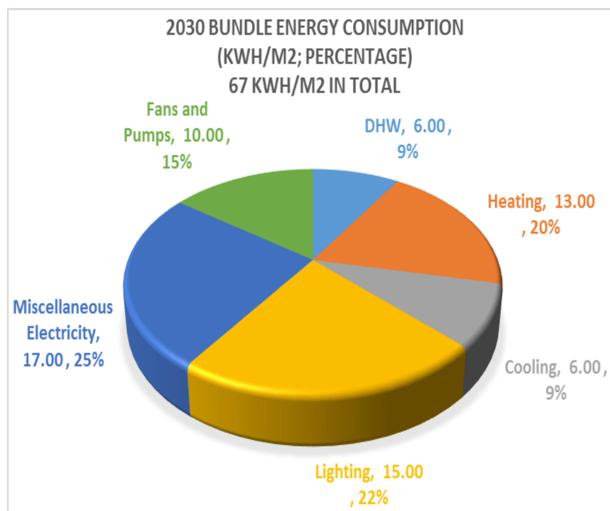
a) 2015



b) 2020

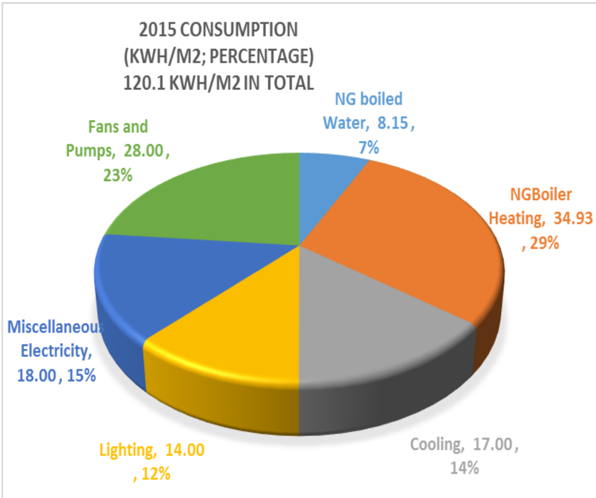


c) 2025

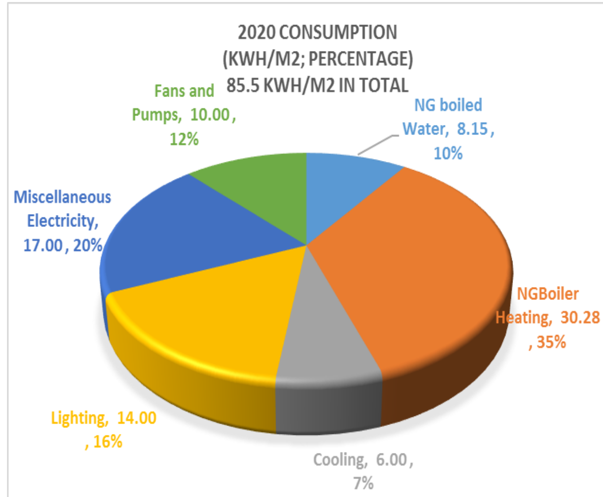


d) 2030

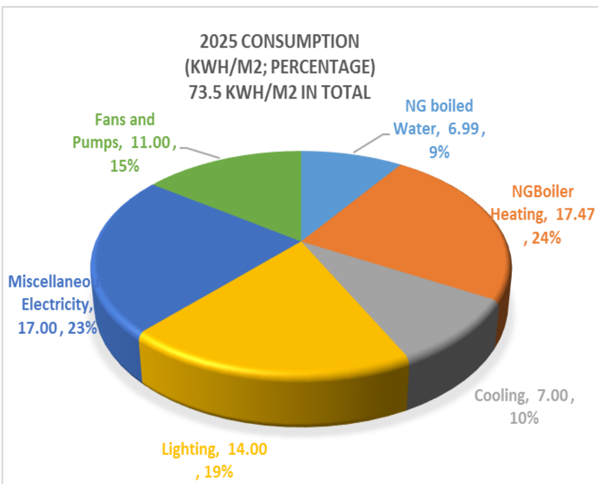
Figure 1 Energy consumption for DES option



a) 2015



b) 2020



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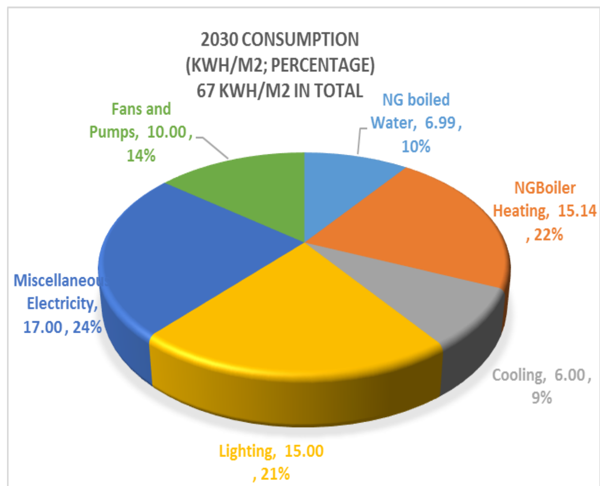

d) 2030

Figure 2 Energy consumption for Natural Gas Boiler option

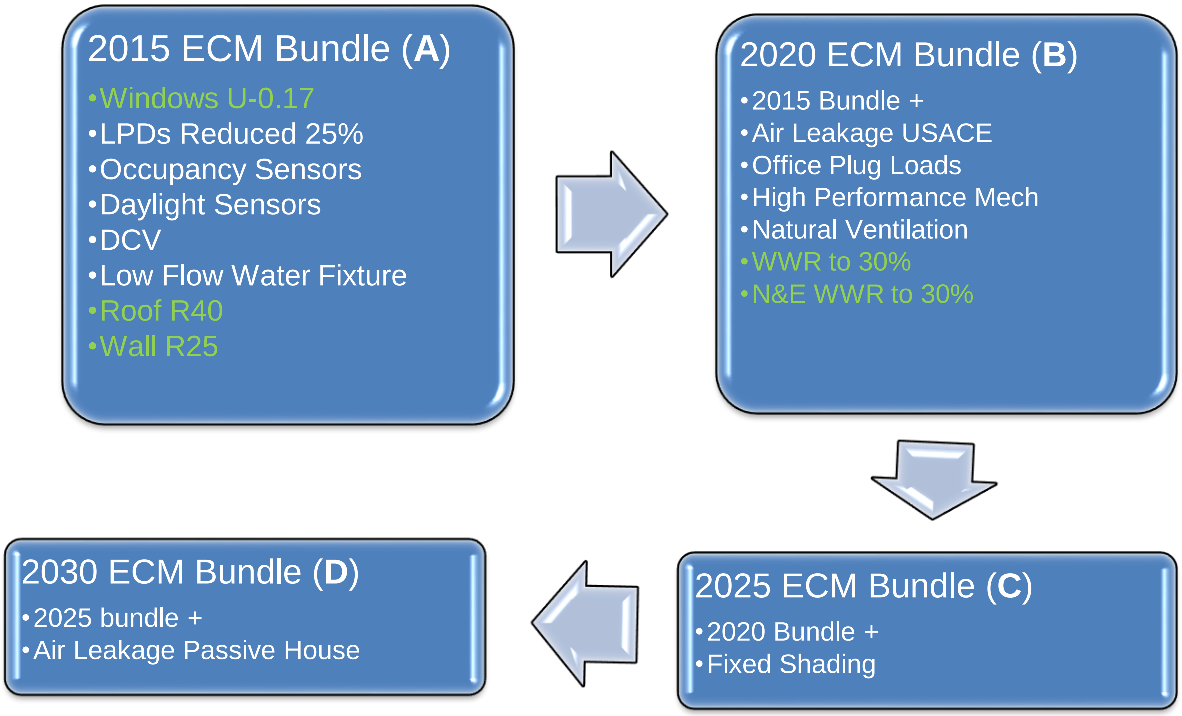

Figure 3. *ECM adjustment to close the emission gap*

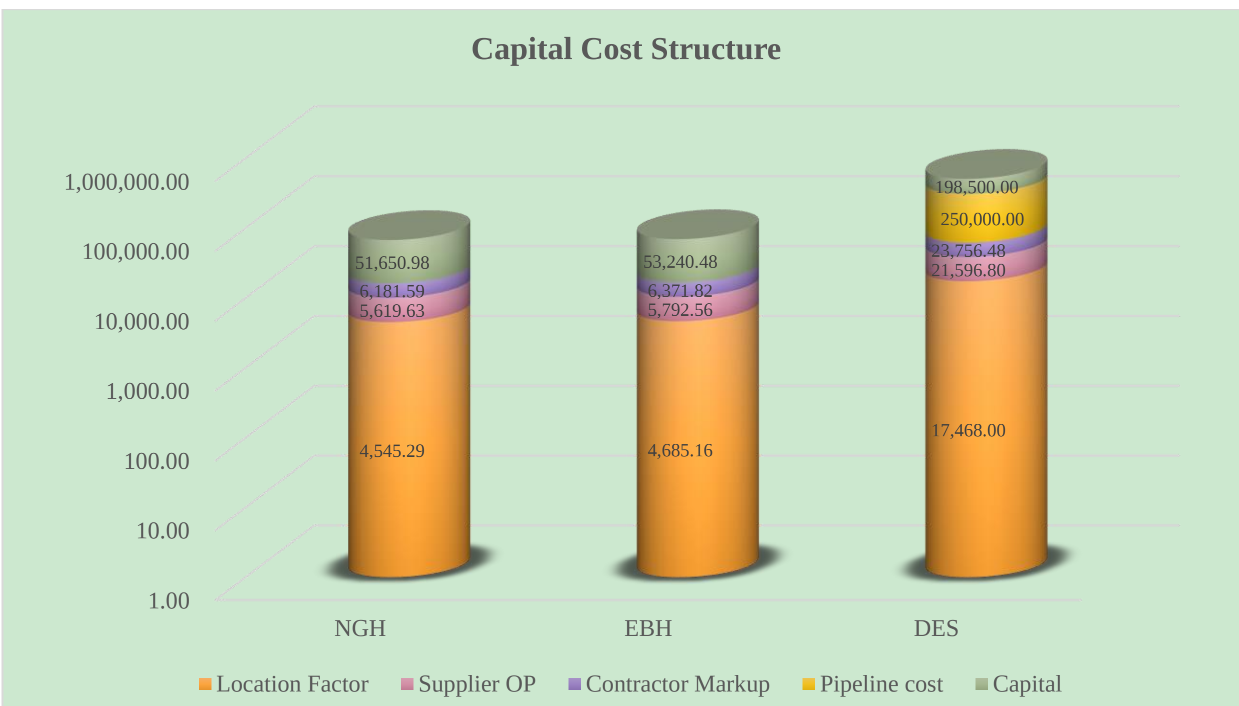

Figure 4. *Capital Cost Structures*

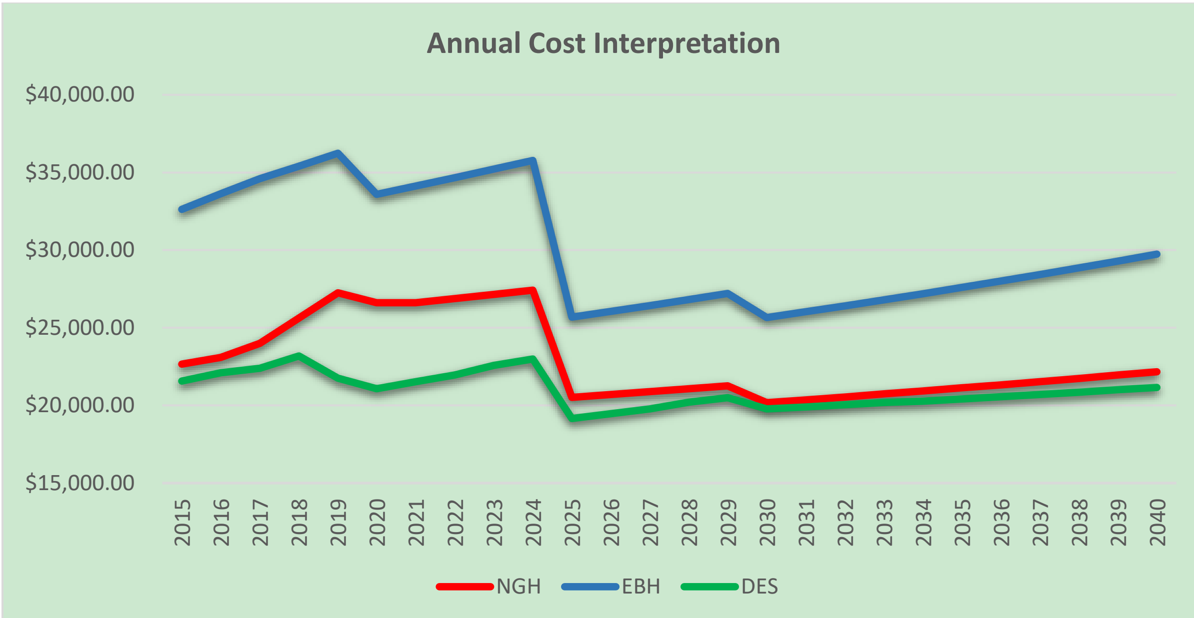

Figure 5. *Total Cost comparison*

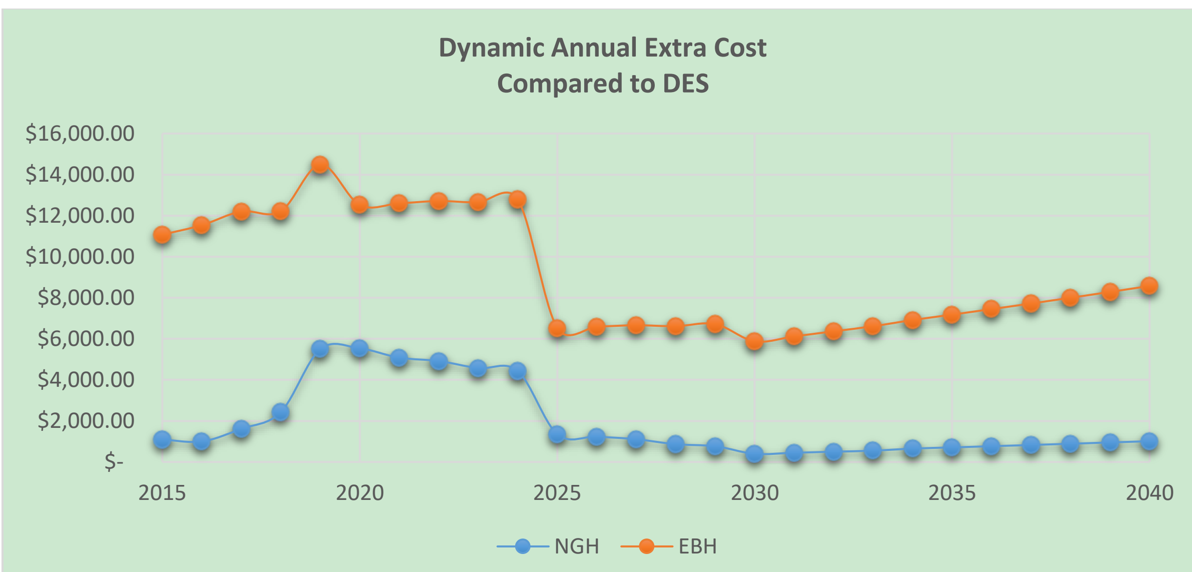

Figure 6. Extra Cost of other heating options compared to DES

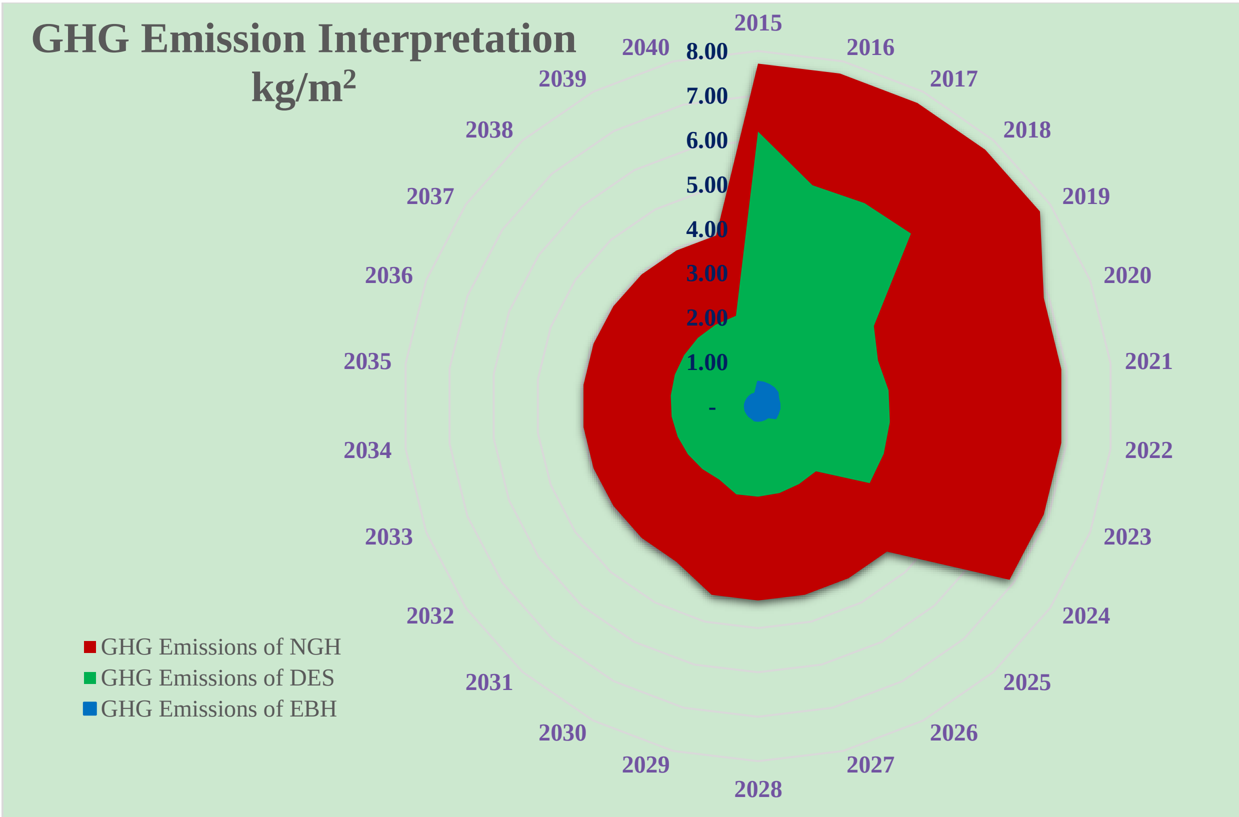

Figure 6. GHG emissions

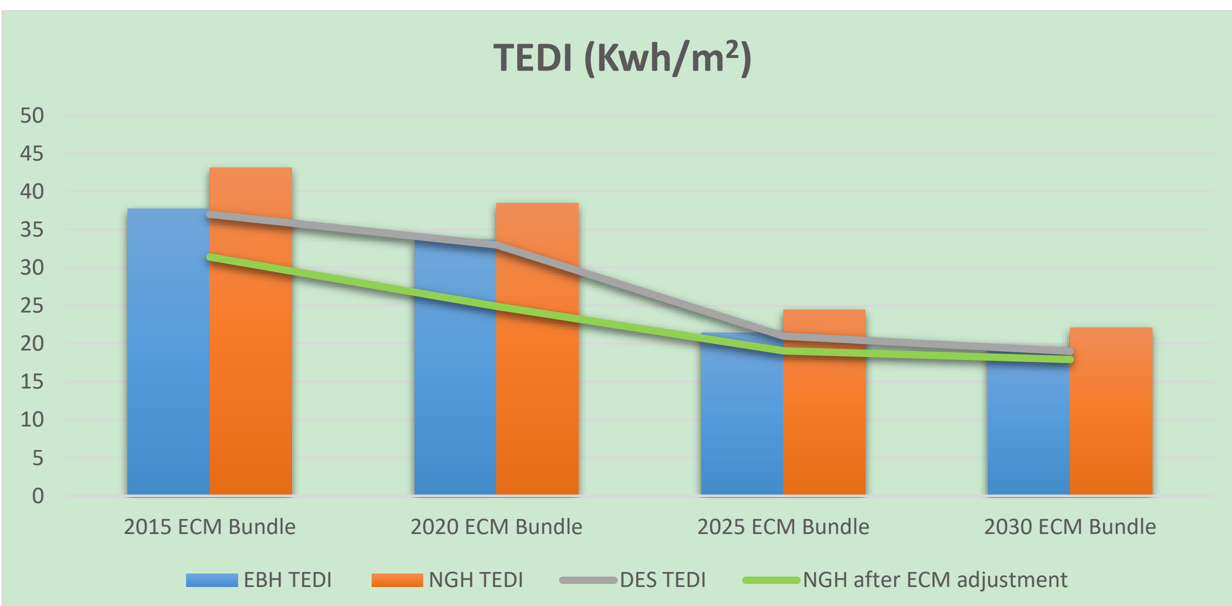

Figure 7 *TEDI*

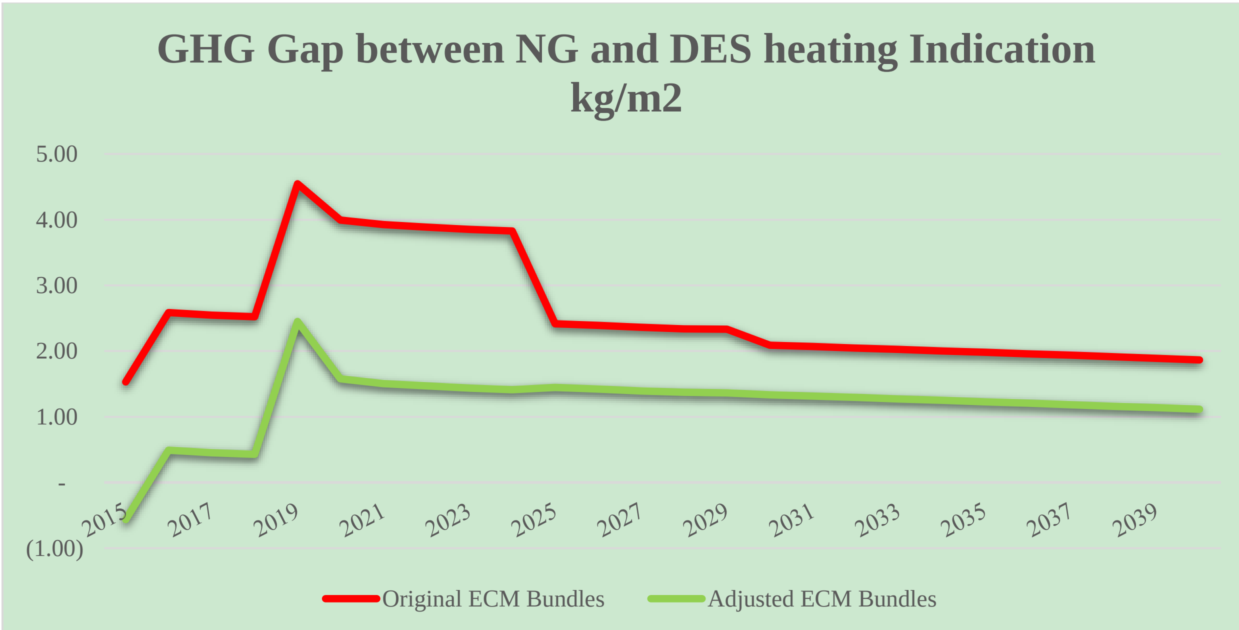

Figure 8. *GHG Gap*

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