Representative Building Energy Study
In Tompkins County
(Office Building)

Version 1.0, September 22, 2017
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1. EXECUTIVE SUMMARY

Taitem Engineering, PC conducted a building energy system study for three types of representative buildings in Tompkins County, NYS. Two types of residential buildings are covered in a separate study. This study includes analysis for the third building type, namely office building. The technologies evaluated consist of boiler/tower water loop heat pump system, variable refrigerant flow (VRF[1]) and ground-source heat pump system (GSHP). VRF is one of the air-source heat pump type that is typically more appropriate to use in office buildings.

The study mainly focuses on the potential energy savings and the cost-effectiveness of the heat pump technologies compared to the conventional system. The energy model is built to examine a 24,000 sq. ft single story office building, which is regarded the representative office setting in Tompkins County.

This report was prepared by Umit Sirt and Ian Shapiro. All questions and comments should be directed to Umit Sirt at (607) 277-1118, ext. 128 or usirt@taitem.com.

[1]: Variable refrigerant flow (VRF) system mainly consists of an outdoor compressor unit and multiple indoor fan coil units. This system has an ability to control the refrigerant flow to multiple evaporators based on the demand and is controlled by a variable-speed drive. VRF systems are capable of simultaneously cooling and heating multiple zones and can recover heat from spaces being cooled for use in spaces being heated and vice versa.

2. FINDINGS

In this analysis, the building envelope components (insulation, etc.) are generally in accordance with the Energy Conservation Construction Code of New York State. High-efficiency heating systems were chosen that meet or exceed the ASHRAE 90.1-2013 standards. The projected building energy consumption for the office building type is shown in Table 2.1.

Table 2.1. Energy Consumption – Office Building

	Electricity Consumption (kWh/yr)	Annual Peak Demand (kW) (in Summer)	Annual Peak Demand (kW) (in Winter)	Natural Gas Consumption (therms/yr)	Site EUI (kBtu/ ft^2/year)
Boiler/Tower Water Loop Heat Pump System	235,483	83.1	-	2,291	43.0
Variable Refrigerant Flow (VRF)	220,679	-	87.8	-	31.4
Ground-Source Heat Pump (GSHP)	199,278	-	68.6	-	28.3

- Site EUI the total energy (as reflected in the utility bills) consumed by the building in one year by the total gross floor area of the building.

In terms of Energy Use Intensities (EUI), the traditional boiler/tower water loop heat pump system option is more energy intensive as compared with VRFs and GSHPs.

The installed cost, energy cost, equivalent annual cost (EAC) and carbon emissions are shown in Table 2.3. Equivalent annual cost is a metric that allows assets of different expected life to be compared on an apples-to-apples basis, accounting for both installed cost and energy cost.

Table 2.3 Equivalent Carbon Emissions and Equivalent Annual Cost – Office Building

	Installed Cost ($)	Energy Cost ($/yr)	Equivalent Annual Cost ($)	Annual GHG Emissions (Metric Tons of CO_2 equivalent)
Boiler/Tower Water Loop Heat Pump System	$480,000	$26,771	$75,145	43.8*
Variable Refrigerant Flow (VRF)	$432,000	$25,672	$71,620	29.6**
Ground-Source Heat Pump (GSHP)	$552,000	$22,688	$77,940	26.7**

*United states Environmental Protection Agency (EPA). "Emission Factors for Greenhouse Gas Inventories" Table 1 - Stationary Combustion Emission Factors. https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf. Last Updated, April 4, 2014.

** United states Environmental Protection Agency (EPA). "Egrid2016 Summary Tables" Table 1. Subregion Output Emission Rates (eGRID2016) Subregion NPCC Upstate NY. https://www.epa.gov/sites/production/files/2018-02/documents/egrid2016_summarytables.pdf. Last Updated, February 15, 2018.

The VRF and GSHP systems have far lower greenhouse gas emissions than the natural gas option.

Non-Cost Tradeoffs

- VRF and GSHP systems are safe when compared to the boilers. There is no risk of carbon monoxide poisoning or gas leakage.
- All systems except for the GSHP system have visible outdoor components, which require cleaning and make noise. The GSHP is extremely quiet outdoors and have no visible outdoor components, but has a compressor in the interior equipment that makes noise, typically located in the basement.
- Both fossil fuel and electric systems will not work when the electric grid is down. Boiler /tower water loop heat pump system need electricity to run fans, pumps and motors.
- For the both of the VRF and GSHP system, the carbon emissions will be less over time as the renewable energy increases (on-site or off-site), or even may approach or equal zero if the customers procure renewable electric energy from the building or community solar.

Comments on Low-Temperature Operation

The capacity and efficiency of heat pumps become lower at lower outdoor air temperatures. This is particularly the case with air-source heat pumps (ASHP), where VRFs is one of the ASHP type (enhanced version of the multi-split system). However, recent developments in heat pumps have increased both their capacity and efficiency at low outdoor air temperatures.

The design temperature for Tompkins County is -2°F (Table 301.1, New York State Energy Code). This means that, statistically, the temperature is lower than -2°F for 1% of the year. In practice, the temperature frequently does not even get this cold. For example, for the winter of 2016-2017, the very coldest temperature was 1°F. Examining historic records from 1893 to the present, for the Cornell weather station, the normal temperature range on the coldest days of winter (January 11 – 26) is between 15°F and 31°F. In other words, on a typical midwinter day, the temperature ranges from 15°F to 31°F. The mean monthly lowest minimum temperature for the period 1883 to the present, for the coldest month (January) is -7°F. In other words, if the very coldest January temperature is taken for each year since 1893 and averaged, it is -7°F. This is consistent with a 99% design temperature of -2°F, which is a little warmer because it represents a temperature for which we design heating equipment, but does not represent the very coldest winter temperature, which occurs for just a few hours of the year. For these few hours, it is deemed acceptable for the heating equipment to temporarily not meet the load, in which case the indoor air temperature will dip below the setpoint (typically 70°F) for these few hours. For the same period of the last 124 years, the absolute very coldest single temperature recorded at Cornell was -25°F, in 1957.

(Source for above data, unless indicated: http://w2.weather.gov/climate/xmacis.php?wfo=bgm)
A common myth is that "heat pumps are not more efficient than electric resistance heat at cold outdoor temperatures." This is simply not the case.

Almost all commercially available air source heat pumps (and VRFs) have performance rating data down to -13 F as standard, and continue to operate even colder than that.

Moreover, this low-temperature operation is much less of an issue for office building types, mainly because the extreme cold weather occurs during at night time, when the offices are typically unoccupied and thermal loads susbstantially low. And therefore, the office electric loads does not align with the peak electric utility loads.

3. ASSUMPTIONS AND METHODOLOGIES

The following assumptions are used in this study.

Energy Modeling and Equipment:

- eQUEST, a DOE2.2 based building energy simulation program is used to establish baseline energy use and to determine energy savings for the proposed design alternatives. This advanced program, which was developed under the sponsorship of the U.S. Department of Energy, applies state-of-the-art features that allow a modeler to enter key characteristics for the building shell, internal gains, and mechanical and electrical systems, along with characteristic operating strategies and schedules. The interactions between all of the different building loads, systems and plants are then simulated in hourly time intervals, using typical long-term average weather data for the location to provide a detailed account of energy consumption and demand. All simulations used Elmira_ Corning – TMY3 (most recent Typical Meteorological Year) weather data, which represents typical year conditions.
- The efficiencies of the HVAC systems are based on ASHRAE 90.1-2013 and are shown in Table 3.1.

Table 3.1. HVAC System Efficiencies

Boiler/Tower Water Loop Heat Pump System	Boiler - AFUE - 85% Heat Rejection Equipment – Axial fan Heat Pump - EER – 13 @ 86F entering water Heat Pump - COP – 4.3 @ 68F entering water
Variable Refrigerant Flow (VRF)	EER – 9.5 - 11 @ 95F db COP - 3.2 -3.3 @ 47F db
Ground-Source Heat Pump (GSHP)	EER – 11 - 13.4 @ 77F entering-water COP – 2.8 - 3.1 @ 32F entering-water

- Lighting power density (LPD) values are based on Energy Conservation Construction Code of New York State.
- Ventilation is based on ASHRAE 62.1-2013.
- Representative internal equipment loads are based on Nonresidential Alternative Calculation Method (ACM) manual, 2008.
- Air-change method (ACH) is used for infiltration, and is assumed to be 0.35 for all the spaces.
- All the HVAC system fans operate as needed in the office building.

- All systems are assumed to be ducted, are located in the condition space, and therefore it is assumed that there are no distribution losses.
- The number of occupants is assumed to be 120.
- All the three options are assumed to use electric appliances. The boiler tower water loop heat pump system option is assumed to use electric resistance instantaneous water heater whereas the VRF and GSHPs options are assumed to use heat pump water heater.

Economics:

- Electricity and Natural Gas rates are assumed to be $0.08/kWh, $9.0/kW and $0.80/Therm respectively year-around, as experienced rates in the local area. The flat charges assumed for natural gas is $24 /month and for electricity is $18 /month.
- A 7.55% discount rate (cost of capital rate) is assumed to calculate equivalent annual cost (EAC). (https://www.propertymetrics.com/blog/2013/09/27/npv-discount-rate/ BY Rovert Schmidt on September 27, 2013)
- In this type of analysis, we might typically account for some escalation (inflation) in fuel and electricity costs in coming years. However, current projections of these costs are difficult. In the past few years, these costs have actually come down. So, we do not assume any escalation in our analysis.
- The estimated useful life of equipment is difficult to authoritatively establish. Different sources give different estimates. Also, different components of a piece of equipment have different useful lives. For example, a geothermal well field might be expected to last 50-100 years because there are no moving parts and the components are safely buried, whereas the associated indoor ground source heat pump that goes with the well field has a shorter life.
- Combining a variety of sources, we assume the useful life for ground source heat pumps is 17 years and for the geothermal well is 50 years, for the boiler tower water loop heat pump system combination is 19 years, and for VRF is 17 years. These lifetime expectancies are utilized in the EAC calculations. Some of the sources we used include:
  - National Renewable Energy Laboratory. "Energy Analysis." Useful Life, March 22, 2016, http://www.nrel.gov/analysis/tech_footprint.html (Accessed April 13, 2017)
  - ASHRAE Owning and Operating Cost Database, http://xp20.ashrae.org/publicdatabase/. (Accessed August 15, 2015)
  - Data obtained from a survey of the United States by ASHRAE Technical Committee TC 1.8 (Akalin, 1978). Some updates in 1986.
- The analysis in this report does not account for subsidies and tax credits that are available for heat pumps. These can be substantial, to the benefit of heat pumps. For example, the federal investment tax credit for ground source heat pumps has been 30% until recently. A new state subsidy for heat pumps has recently been introduced.
- In estimating the carbon emissions of natural gas equipment, we use a national-average factor from EPA (United states Environmental Protection Agency (EPA). "Emission Factors for Greenhouse Gas Inventories" Table 1 - Stationary Combustion

Emission Factors. https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf. Last Updated, April 4, 2014.). It should be noted that there is evidence that methane leaks in the natural gas production and distribution system may well result in higher carbon emissions. So, the estimated impact on carbon emissions in this report might be considered as being on the low side.

- All equipment is sized with sufficient capacity to meet midwinter heating design loads. The VRF system has electric resistance backup, that is minimally used at outdoor conditions below midwinter design temperatures, and this energy usage is accounted for in the results.

Authors

Umit Sirt, PE, CEM, BEMP, HBDP **Partner, Senior Energy Engineer**

Umit is responsible for managing and overseeing the Energy+Sustainability department, which performs benchmarking, energy studies, advanced energy models and investment-grade energy audits, technical reviews of energy studies, energy master planning, and outreach for energy efficiency. Umit was selected as one of the top 40 engineers in the U.S., under the age of 40, in 2014. Umit brings over 15 years' experience in the thermo-fluid field with a specialty in energy and HVAC-R. He has gained a reputation for quality energy auditing and high-performance design consulting. He is especially interested in building science and energy system assessments with simulation and modeling. He has built compliant energy models and given assistance to design teams for LEED and ESTIDAMA projects. He is one of the first HBDPs (High-performance Building Design Professional) in NY State and is also one of the provisional assessors in ASHRAE'S Building Energy Quotient Pilot Program (called Building bEQ). Umit published an article in ASHRAE Journal in October 2011 that discusses HVAC selection for envelope-dominated buildings. He also had given presentations nationwide that includes net-zero building design, high performing HVAC system selections, elevator controls, and tax deduction in energy efficient commercial buildings. Umit holds a B.S. in Mechanical Engineering from METU in Turkey and an M.E. in Mechanical Engineering from Stevens Institute of Technology in New Jersey.

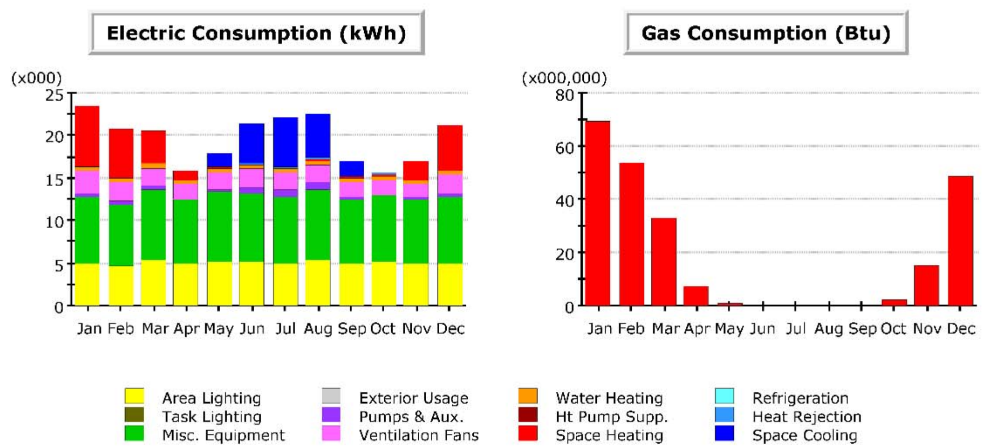
Ian Shapiro, PE, LEED AP **Founder, Senior Engineer**

Ian founded Taitem Engineering in 1989. He has led several applied energy conservation research projects, has led many design and energy projects, and has delivered workshops in the area of energy and ventilation. He has also led the development of several computer programs which are used in the HVAC, energy, and indoor air quality fields, including TREAT (Targeted Residential Energy Analysis Tools), which was awarded the 2005 national R&D100 Award. Prior to starting Taitem Engineering, he worked for seven years at Carrier Corporation in Syracuse, where he designed heat pumps and air conditioning equipment, and holds eight patents from this work. He is the co-author of the books *Green Building Illustrated* (2014) and *Energy Audits and Improvements for Commercial Buildings* (2016), both published by Wiley. He has been a visiting lecturer at Cornell University, Tompkins Cortland Community College, and Syracuse University. He holds an undergraduate degree from McGill University, and an M.S. from Columbia University, both in mechanical engineering. Ian is a licensed engineer in the states of New York, Connecticut, Pennsylvania.

APPENDIX A – ENERGY USE AND COSTS FOR DIFFERENT ALTERNATIVES

Office Building - Boiler/Tower Water Loop Heat Pump System

Project/Run: Representative Study Office Building BT 09 14 2017 - Baseline Design   Run Date/Time: 09/22/17 @ 11:15



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.00	0.01	0.03	0.06	1.45	4.77	5.66	5.21	1.72	0.14	0.02	0.02	19.09
Heat Reject.	-	-	-	-	0.09	0.25	0.30	0.28	0.10	0.01	-	-	1.04
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	7.09	5.77	3.87	1.03	0.20	0.06	0.04	0.06	0.12	0.33	2.15	5.43	26.16
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.51	0.50	0.60	0.52	0.53	0.48	0.41	0.44	0.38	0.42	0.44	0.48	5.71
Vent. Fans	2.60	2.26	2.13	1.70	1.90	2.02	2.04	2.06	1.82	1.72	1.71	2.27	24.24
Pumps & Aux.	0.57	0.46	0.30	0.07	0.28	0.78	0.91	0.84	0.29	0.04	0.15	0.43	5.12
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	7.76	7.18	8.30	7.64	8.12	7.99	7.77	8.30	7.64	7.94	7.63	7.77	94.04
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	4.89	4.58	5.39	4.87	5.22	5.17	4.91	5.39	4.87	5.06	4.84	4.91	60.09
Total	23.42	20.77	20.63	15.88	17.79	21.52	22.04	22.58	16.94	15.66	16.95	21.31	235.48

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	69.02	53.46	32.71	7.24	0.90	-	-	-	0.15	2.02	14.71	48.91	229.11
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	69.02	53.46	32.71	7.24	0.90	-	-	-	0.15	2.02	14.71	48.91	229.11

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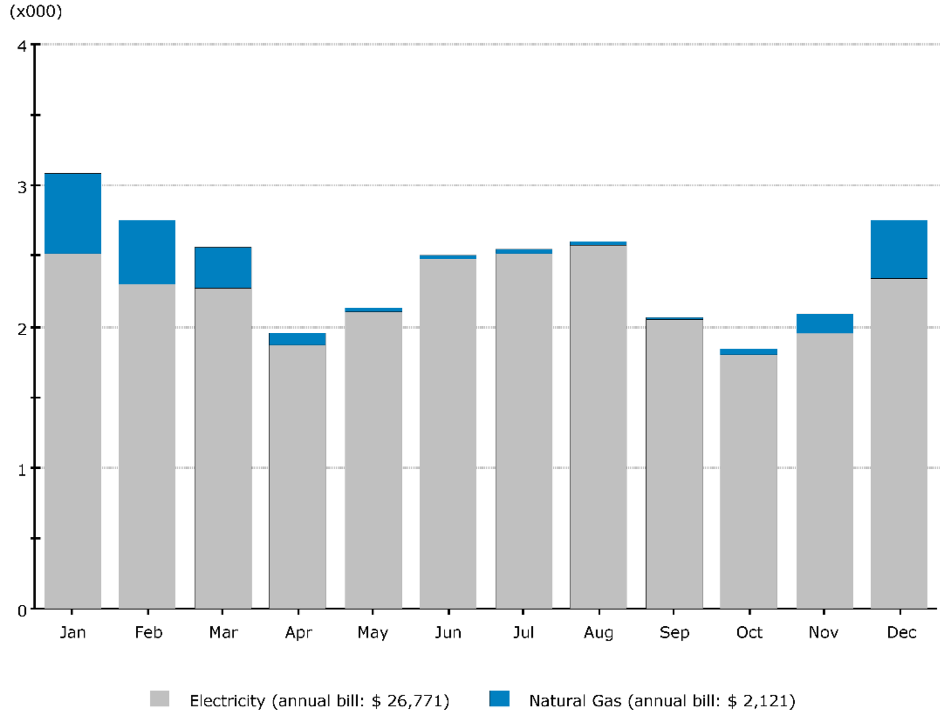
Project/Run: Representative Study_Office Building_BT_09_14_2017 - Baseline Design   Run Date/Time: 09/22/17 @ 11:15

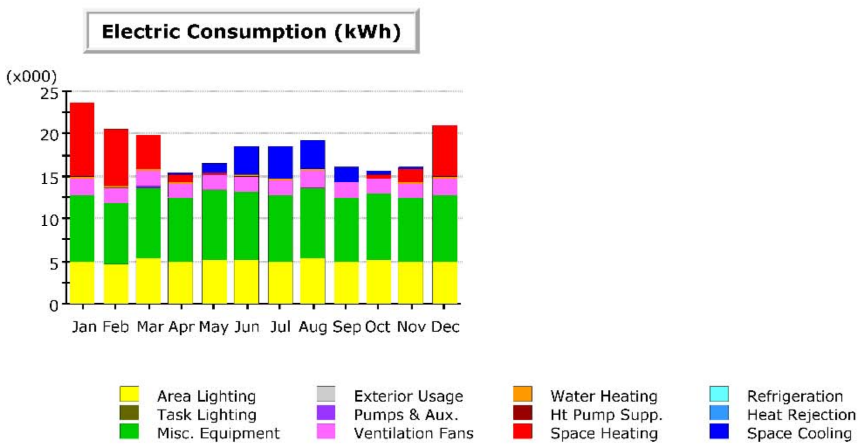
Monthly Utility Bills ($)



Total Annual Bill Across All Rates: $ 28,892

Office Building - Variable Refrigerant Flow System (VRF)

Project/Run: Representative Study Office Building ASHP 09 14 2017 - Baseline Design   Run Date/Time: 09/22/17 @ 03:28



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.01	0.01	0.08	0.19	1.16	3.38	3.80	3.51	1.65	0.58	0.05	0.01	14.44
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	8.54	6.61	3.99	0.85	0.11	-	-	-	0.02	0.26	1.70	6.07	28.16
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.19	0.18	0.21	0.19	0.18	0.17	0.15	0.16	0.15	0.16	0.17	0.18	2.10
Vent. Fans	2.14	1.83	1.90	1.60	1.71	1.79	1.81	1.89	1.65	1.60	1.55	1.96	21.45
Pumps & Aux.	0.04	0.04	0.05	0.06	0.02	0.01	0.00	0.00	0.02	0.05	0.06	0.05	0.40
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	7.76	7.18	8.30	7.64	8.12	7.99	7.77	8.30	7.64	7.94	7.63	7.77	94.04
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	4.89	4.58	5.39	4.87	5.22	5.17	4.91	5.39	4.87	5.06	4.84	4.91	60.09
Total	23.57	20.43	19.92	15.39	16.53	18.51	18.45	19.25	16.00	15.66	16.00	20.95	220.68

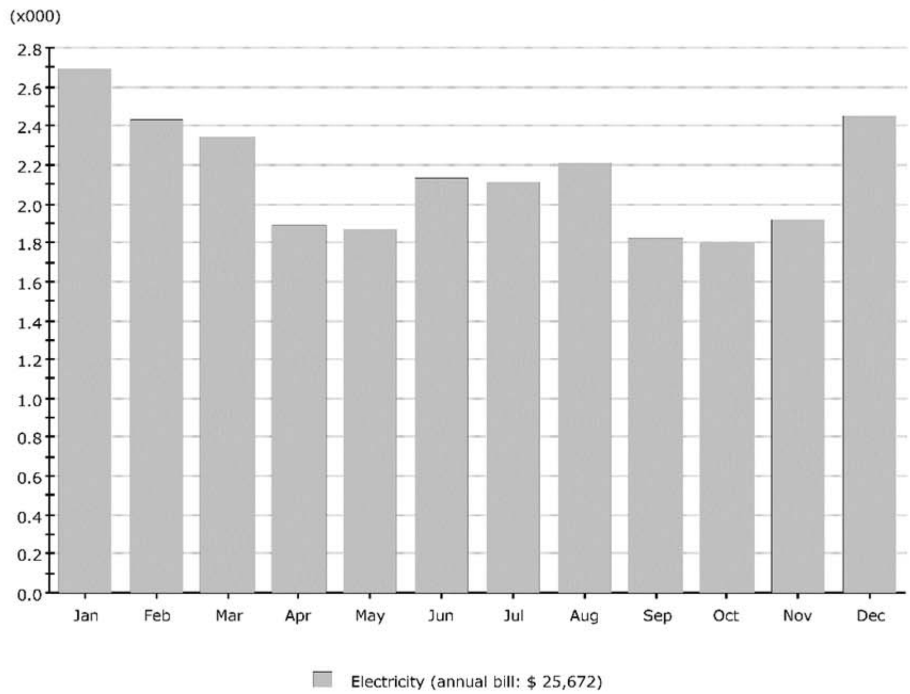
Gas Consumption (Btu)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													

eQUEST 3.64.7130   Monthly Energy Consumption by Enduse   Page 1

Project/Run: Representative Study Office Building ASHP 09 14 2017 - Baseline Design Run Date/Time: 09/22/17 @ 03:28

Monthly Utility Bills ($)



Total Annual Bill Across All Rates: $ 25,672

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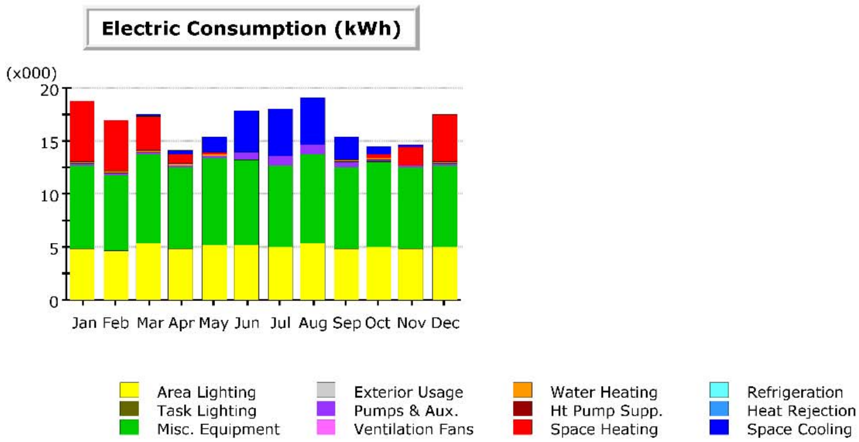
Office Building - Ground Source Heat Pump (GSHP)

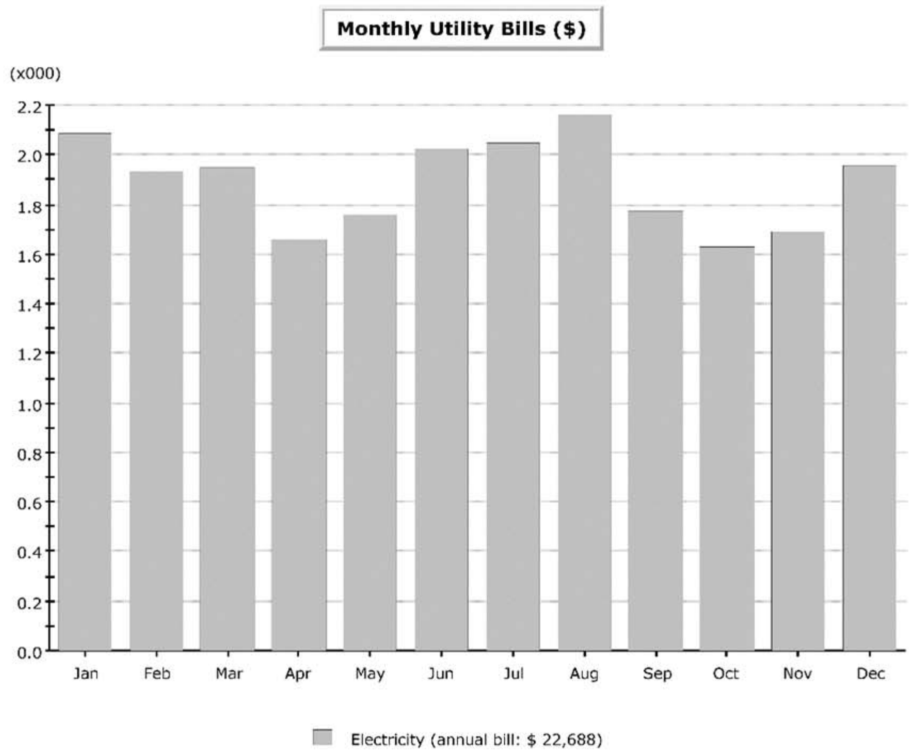


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.01	0.01	0.09	0.25	1.43	3.90	4.44	4.39	2.13	0.72	0.07	0.02	17.45
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	5.77	4.89	3.35	0.94	0.16	0.01	0.01	0.00	0.03	0.31	1.77	4.42	21.65
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.05	0.06	0.11	0.18	0.11	0.04	0.04	0.04	0.06	0.11	0.09	0.06	0.95
Vent. Fans	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08
Pumps & Aux.	0.27	0.23	0.21	0.15	0.29	0.77	0.87	0.95	0.59	0.26	0.17	0.24	5.01
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	7.76	7.18	8.30	7.64	8.12	7.99	7.77	8.30	7.64	7.94	7.63	7.77	94.04
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	4.89	4.58	5.39	4.87	5.22	5.17	4.91	5.39	4.87	5.06	4.84	4.91	60.09
Total	18.76	16.95	17.46	14.02	15.34	17.89	18.05	19.08	15.32	14.40	14.57	17.43	199.28

Gas Consumption (Btu)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													



Total Annual Bill Across All Rates: $ 22,688