netZERO

IPRO 317 Green Home Design
Fall 2009

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The Interprofessional Projects (IPRO®) Program at Illinois Institute of Technology

An emphasis on multidisciplinary education and cross-functional teams has become pervasive in education and the workplace. IIT offers an innovative and comprehensive approach to providing students with a real-world project-based experience—the integration of interprofessional perspectives in a student team environment. Developed at IIT in 1995, the IPRO Program consists of student teams from the sophomore through graduate levels, representing the breadth of the university's disciplines and professional programs. Projects crystallize over a one- or multisemester period through collaborations with sponsoring corporations, nonprofit groups, government agencies, and entrepreneurs. IPRO team projects reflect a panorama of workplace challenges, encompassing research, design and process improvement, service learning, the international realm, and entrepreneurship. (Refer to http://ipro.iit.edu for information.) The IPRO 317 Green Home Design team project represents one of more than 40 IPRO team projects for the fall 2009 semester.

Executive Summary

This report summarizes the work of a multidisciplinary undergraduate student team organized via the Interprofessional Projects (IPRO) Program at Illinois Institute of Technology. The work was conducted during the fall 2009 semester which spanned a 14-week period from August through December 2009.

This IPRO was sponsored by Mr. Jimmy Eng. Mr. Eng is a realtor in the city of Chicago. He is also an alumnus of the Illinois Institute of Technology. Mr. Eng presented the group with a very interesting and challenging problem—that of designing a net zero energy, zero carbon emission, high efficiency green home at a competitive cost relative to neighboring units. The building is to be a three-unit condominium building on a specific 100 ft. by 25 ft. Chicago-style lot. The given site, 1114 W. Roscoe St, Chicago, IL is situated on Chicago's North Side, adjacent to an alley and the CTA Brown Line tracks. Pictures of the existing Building are attached as Appendix A. More specifically, the client requested a "non-disposable" design with a minimum three hundred year design life. His desire is for the building to allow for lower maintenance fees over the lifespan of the building, maximum physical and psychological comfort, zero energy use and zero carbon emission, as well as looking beyond existing building codes and technologies. In addition, the sponsor required that the cost of construction be comparable to similar sized structures in the area, which is approximately $1.7 million construction cost for a three flat building.

The challenge of the IPRO team was to identify the most cost effective and energy efficient materials, construction methods, and products for this project. When combined, all of these elements should result in our desired net zero home. Additional challenges included accommodating the needs of the client within the short timetable of one semester.

The IPRO team was split into multiple subgroups. Each subgroup worked together under subgroup team leaders to accomplish specified goals throughout the course of the semester. Information from existing green technologies, literature, and journals pertaining to the strength of materials, as well as other relevant design information available, were gathered and used as part of our research. Each team consulted with experts in the fields when needed to supplement their research.

Throughout the course of our research and investigations, a variety of different software was used to aid in our design. eQUEST (Energy Modeling Software) was used to estimate and analyze the overall energy usage of the building. MathCAD assisted in any structural calculations that needed to be done as well as calculating the overall R-values for the building. AutoCAD was utilized to draft all elements of the building, which include architectural and structural components. Revit and ArchiCAD were also used for 3D modeling and architectural problem solving. Additionally, the building was designed in accordance with the Chicago Building Code. Other codes accepted by the city of Chicago were used as well.

This IPRO concluded that the given site is one of the largest limiting factors in creating a high performance energy efficient building. Through our research efforts we have discovered the large importance of envelope design related to heating and cooling. The use of a standard building design to use as a reference point was essential in evaluating each design choice all along the way. One aspect of our design is realizing the need to educate the user, ensuring the residents are conscious of the energy used by everyday appliances. We recommend that as the next steps in designing high performance energy efficient buildings to continue further research on newer and more innovative technologies as could apply to our conditions. We would also recommend that future groups be smaller in size for better allocation of tasks to ensure everyone is working at every step of the process. One final note to future IPROs tackling this dilemma is to utilize technologies available to aid in analysis of the entire building.

Purpose

Our sponsor, Jimmy Eng, posed us with a challenging opportunity to combat the ever growing environmental problems in the world today. More specifically, he asked us to target the residential aspect of this problem by coming up with a design for a sustainable net-zero home that would revolutionize the housing industry. Jimmy specifically stressed the importance of minimizing energy usage through optimization of design and operation rather than just compensating for the energy loads on the house through alternative methods. He also pointed out that while most people are pro-environment, they are not willing or able to afford the unnecessarily expensive green homes that exist or implement green solutions on their current homes, especially when most current solutions don't have very long life spans. It is for this reason that we aim to design a long-lasting house at a competitive price to the surrounding homes.

The term “net-zero” has a disputed definition but for the purposes of our report, we will take it to mean net-zero energy usage and net-zero carbon emissions by the house alone. While we understand that net-zero could be taken to include the production and disposal of materials, for the purpose of our project we will be narrowing in on this specific aspect of net-zero. Sustainability also has a lot of ambiguity associated. We have taken sustainability to be a two part facet of our project: the core value of sustainability, that is to say providing for the needs of now without compromising the needs of the future by way of minimizing consumption of non-renewable resources and reducing amount of non biodegradable waste, and the second being education as we may have the means to achieve sustainable design, it means very little if the users don’t utilize it accordingly.

This holistic design approach is very rarely taken by most conventional home builders. We hope to develop a methodology for green home design that may be adopted by others and used to promote and develop other environmentally friendly homes.

Organization

In the first several meetings of the semester, the organization of the Net Zero IPRO team was very free-form insomuch as everyone worked as a cohesive unit towards a common goal. The work done at the time was largely directed by the sponsor, Mr. Jimmy Eng to help everyone to arrive at a unified idea of what we are working towards. Once this criteria was satisfied and all members had come to their own conclusion about the meanings of terms such as 'sustainable,' 'durable,' 'net-zero energy,' and 'net zero carbon emissions,' the teams were broken up into four initial subgroups. For each of the three main phases of the project, the sub-groups would divide and sub-divide into new groups while moving through the process.

The first stage was Research. The basis of the research was to find the best possible route to net-zero energy with the lowest cost and the highest reward. The second phase was a compilation point where the groups came together to discuss the research completed with the sponsor and move forward with new ideas. The groups subdivided again for the second phase to work specifically with the structure of the building to make it more sustainable. In the final phase of the project, there were ultimately three groups working to prove that the building was zero energy, get cost estimates, and create a final design. The details of these groups will be expounded upon in the following paragraphs.

For the first phase, group leaders presented themselves over time but ultimately the group worked together as a whole towards an end goal. These initial groups were Materials Research, Site Analysis, Systems and Structure Integration and Existing Structures Research. These groups were responsible for the initial research so that an idea could begin to form of the final product. The goal was known but how to get there was the process that needed to be taken. The groups did research and every week or so there would be an informational discussion so that each group was aware of the research being done by another group. This created a smooth flow of information. Towards the end of this phase there were small presentations on the decisions reached by the different groups about the framework of the idea. The main type of research used by all groups included library and database research using articles for information regarding zero energy homes and buildings.

Continued involvement from Mr. Eng led sub-groups into different directions such that the groups spit and reformed into new sub-groups. These groups were responsible for finding the best way to insulate the building, the most efficient heating, ventilation, and air conditioning (HVAC) system options, and ways to optimize the structure of the building to play on passive design techniques as well as continued improvement on the overall design and preferences involved with each unit. During this phase special emphasis was placed on the fact that it had been decided that the design would be a concrete structure. With that, the comfort and aesthetic appeal of the structure inside and out had to be considered for a marketable appeal to a potential client. Catalogues were researched to find products for the insulation methods and types of concrete, siding, et cetera.

As the third phase began, the sub-groups again shifted down to three technical groups working as one group. The work that the eQUEST group was doing heavily depended upon the work of the other two groups as their work decided what eQUEST needed to calculate. There was one team researching, one team designing and one team calculating. The research team at this point was specifically looking for the most efficient options for appliances, lighting systems, water heaters, HVAC, and insulation of the structure. This was the most crucial phase as it came down to this to discover if the structure designed would actually be zero energy under certain conditions. These calculations are run with the use of eQUEST. The eQUEST group diligently worked to take all of the data and the desired design and compile it into a design that would calculate, given the parameters needed, net energy consumption for the structure. During this phase the catalogues were used again to find products to furnish the apartment

Analysis and Findings

In analyzing our approach, the Mechanical team researched the most energy efficient ways to produce necessary heating and cooling to the building. In our research we found, in AHSRAE Journal "Getting to Net Zero", different approaches to saving energy and/or maximizing energy usage. Acknowledging that much of the project's goal rested on our group's shoulders, we got to work and tapped into our resources and discovered that reaching net zero energy could be achieved by reducing the magnanimous use of energy in a building. This had to be done without using fuel generated appliances. We found our best options by using energy modeling software and testing our options. We accomplished our goal in achieving net zero with the help or our total IPRO team and here's how.

In our research phase, as we mentioned in our presentation, we came upon different heating and cooling options and found the most efficient ones. These options include floor radiant heating and cooling, a geothermal heat pump or turbine with vertical or horizontal bores in combination with a forced air system, and indirect heating using condensing boilers. All of these options are very efficient and our group did an outstanding job on finding the most usable products for our Green House. In addition to research of technology we also looked into pre existing green homes to see what we could take away from them (see appendix 3)

The radiant heating and cooling option that has been used for centuries and still pervades the industry as a primary heating option that is efficient and known to heat the person not the space as conventional heating sources do today. According to the Department of Energy, there are three types of radiant floor heat: radiant air floors, electric radiant floors, and hot water radiant floors, where air, electricity and hot water or fluids are the heat carrying medium. "All three types can be further subdivided by the type of installation: those that make use of the large thermal mass of a concrete slab floor or lightweight concrete over a wooden subfloor (these are called "wet installations"); and those in which the installer "sandwiches" the radiant floor tubing between two layers of plywood or attaches the tubing under the finished floor or subfloor ("dry installations")." For a larger thermal mass, we concluded that using concrete floor slabs was the solution most favorable if we were to use the option of using radiant heating. We concluded that using water or R134a fluid for their thermal retention qualities we could maximize the use of radiant heating and heat the space adequately. The most widely used product to evenly distribute this heating is PEX tubing. A heat pump to distribute the fluid through this tubing that has high thermal conductivity allows for the space to be heat evenly and effectively.

Our next heating and cooling option that we obtained research information on was the geothermal heat pump also known as ground source heat pump. To understand better the idea of ground source heat pump technology, one must understand that the ground source heat pump is a system that acquires central heating and cooling that is pumped through a heat medium to or from the ground. It uses the earth as a heat source in the winter and a heat sink in the summer. This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems. DX coils for cooling, and DX coils (heat pump) for heating were seen as the best options to use for use when we concluded our research on this technology.

Indirect Heating while using a furnace is another consideration we saw as an option. We found efficient boilers where the maximum efficiency attained could reach up to 95%. Unfortunately, these boilers used fuel emitting carbon emission, whereas this would not help us obtain our goal of zero carbon emissions. We investigated electric furnaces and decided to consider using this approach for heating especially when modeling the total energy of the building.

The primary resource used in analyzing the energy usage for heating and cooling was eQUEST energy modeling software. This software allowed us model the different HVAC equipment options we considered implementing in the Green House design. We started with an electric furnace knowing that it may not be the most efficient option for a base case. We then considered radiant heating and lastly the ground source heat pump option.

In order to calculate energy loads for each building unit, we investigated and compiled an appliance energy usage spreadsheet that accounted for the kWh / month for each item used in a unit. (See Appendix 1) We complied this by estimating how much possible lighting and plug load energy usage would be used for each room in each unit including mechanical appliance such as heat pump, furnace, water heater, sump pump and et cetera depending on the HVAC system selected. An innovation solution directly related to kWh used in design where lighting is concerned is that we decided to use compact fluorescent lights and incorporate day lighting where incident lighting can make up for much for normally used electric lighting. Motion sensors are also incorporated into the design as well to only use lighting when there is motion in the space. Adequate lighting design was done to adhere to the needs of tasks normally done in residential space. The class aided in compiling this appliance sheet by finding the most efficient appliances on the market from Energy Star GE product and other top of the line green industry leaders. For each appliance the average number of hours used per day was documented and used in calculations to obtain the kWh/ month.

Our discoveries concluded that by using these appliances, lighting solutions, and using DX coils for heating and cooling where there is supplemental cooling through cooling coils, we can use under 2000 kWh/month in a typical Chicago climate, as per the site our sponsor posed us with (see appendix 4).

One particular innovative approach was that we ran numerous simulations in eQUEST in order to obtain the most proficient solution for obtaining the lowest energy consumption possible. We conducted interviews with an eQUEST representative to ensure we were using the program correctly as it was the first time being introduced to the program for many of the students. Before running our simulations and in our research phase, our team members contacted companies that design geothermal systems as well as radiant heating to get a general idea as to what options we had for a residential building, what was common and what had yet to be investigated. We even asked about combination systems including radiant and geothermal. We feel that discussing theses options with professionals in the field was an innovative approach in that by consulting with many different people we were able to think beyond the bounds of conventional heating solutions. Also, eQUEST allowed us to take into account various appliances around the house. So for each iteration of testing we used different appliances from our complied list (appendix 2). The results of eQUEST can be seen in appendix 5

We feel we accomplished what was necessary to make sure the building's energy usage was kept to a minimum by choosing low energy appliances, choosing the most practical HVAC for our green house, and using a system that can model our energy usage. The energy supply through our chosen energy sources adequately covers the energy usage for this building and will be explained further. This allows us to be net zero energy, because our energy consumption is equal to our building's generated supply.

In order to find a more suitable power solution we created a spreadsheet to help us keep track of power loads. This spreadsheet contained a basic plugged load (energy usage all appliances and electronics plugged into the outlet) of the house. We had to keep in mind that it was a three person flat and that there would be miscellaneous variables such as alarm clocks and computers that would not necessarily be the same for everyone. The data from this spreadsheet was used with eQUEST in order to come up with our energy usage per month in terms of kwh (kilowatt hours). We then used this number to trigger another spreadsheet which, in a way, can be used as a template for green home design. This spreadsheet takes an energy usage and given various types of solar panels and wind turbines, will calculate area needed for solar panels, number of wind turbines and pricing for both. Additionally, a way of calculating hybrid systems was also incorporated. So for a given roof area (presumably the area where you can put solar panels) it will tell you how much energy you can get from the solar panels and how many additional wind turbines you would need in order to reach your energy goal. It should be noted that the values used for these calculations revolve around ideal conditions and the actual numbers will vary, but we believe that through the use of net metering we should come out fairly close to our target in the end. Net metering is a way of connecting a house to a power grid such that when a house's energy systems are producing a surplus of energy (more energy than the house itself is consuming) the power meter on the house will spin backwards and make up for the energy used by the house when the house's systems are not producing enough energy. Theoretically, the net energy used each month should be zero.

Conclusions

In the end we were able to determine some things about home design that we believe to be important when designing a green home. The first of which is energy usage. Energy consumption in a building is greatly affected by the amount of energy used by the residents. The residents must be conscious about how much energy they are using because the use of every day appliances makes a large impact on energy consumption. Secondly, one must consider the site. After extensive site analysis we were able to determine that one cannot simply throw together all the most efficient products and materials and end up with a green home. The orientation, dimensions, and location of a site can greatly affect the area. For example, one must take into consideration the soil composition, water table, north-south facing vs east-west for sun exposure and height restrictions just to name a few of the issues that arises from having a bad site. After analyzing a site and determining what you can and cannot use there, you need to determine what you should use. This is a complicated and involved step as we learned that with every positive aspect of a design there is a negative one to counteract it and that you must learn to determine when the goods outweigh the bad. Furthermore, you need to take into consideration the envelope or the shell of the house. The envelope will affect the choices you make for the electrical and heating and ventilation systems. So it is important to choose an optimal material for the house that optimizes your net usage. Designing and optimizing the envelope also depends on the number and placement of windows, minimizing exterior wall area, orientation et cetera. This is why we turned to the energy modeling software. In order to get started, we found you need to start with a base design for a building. This design doesn't need to be perfect as you will modify the design and through an iterative process of modeling and revising the design you can reach your energy goal. This process also helps in determining the positive and negative effects of certain systems. Another issue we had to deal with is effective communication between the large amounts of people involved. We found that dividing into smaller subgroups and delegating each group a task for coming up with various green solutions of specific categories, you can then do the iterative modeling tests and come up with a final design.

Furthermore, we aimed to create a template for green home design, and while this objective did not fully come to fruition, the spreadsheet made provides an easier way of making green homes. It should also be noted that the values in the spreadsheet can be easily changed out with new improved technologies as they are constantly becoming available.

Appendices

Appendix 1: Energy Source Spreadsheet (uploaded as separate file)

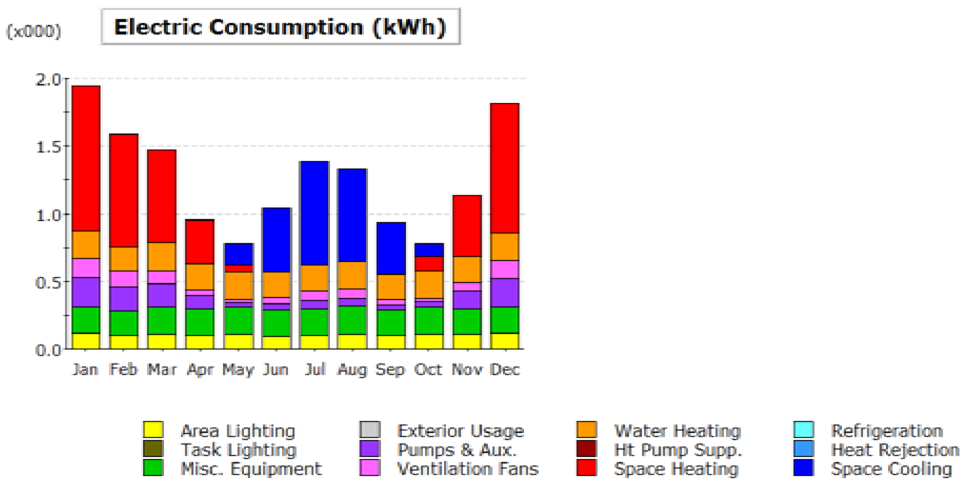
Appendix 2: Appliance List (uploaded as separate file)

Appendix 3: Case Studies (uploaded as separate files)

Appendix 4: House Location

1114 W Roscoe, Chicago, IL 60657

Appendix 5: eQUEST results

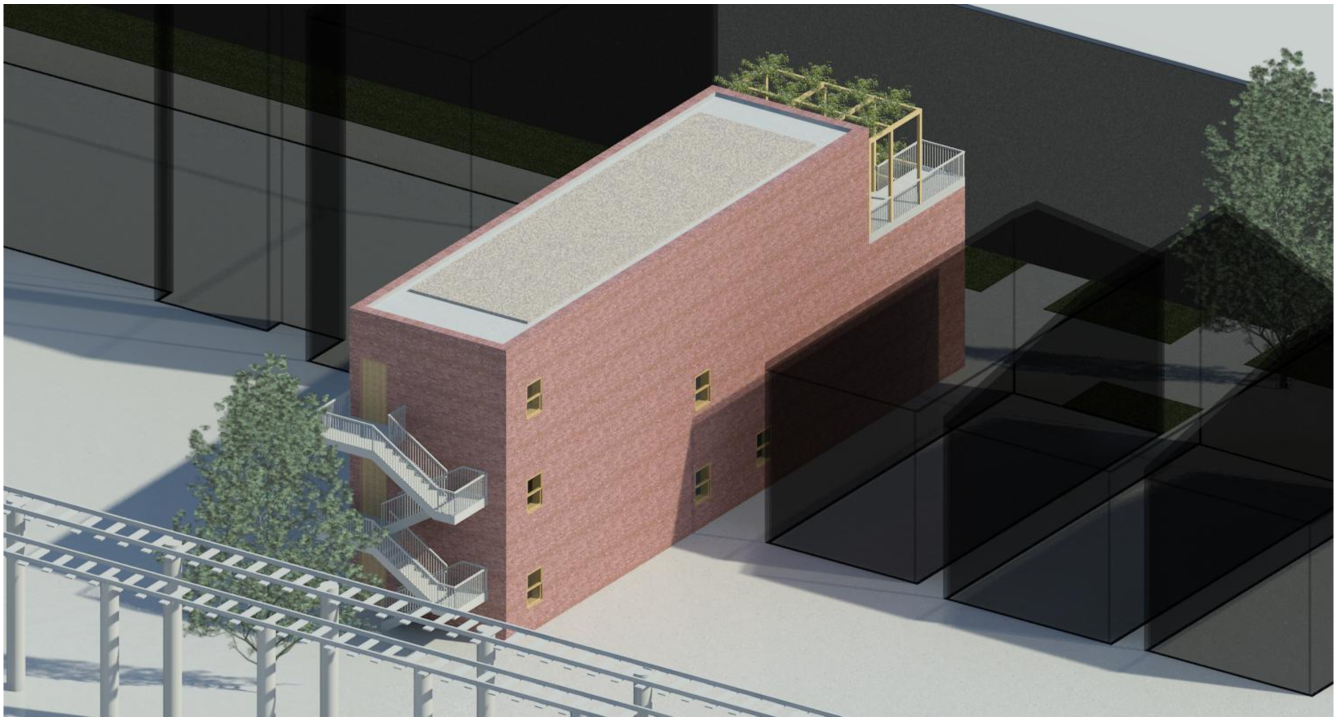


Electric Consumption (kWh x000)

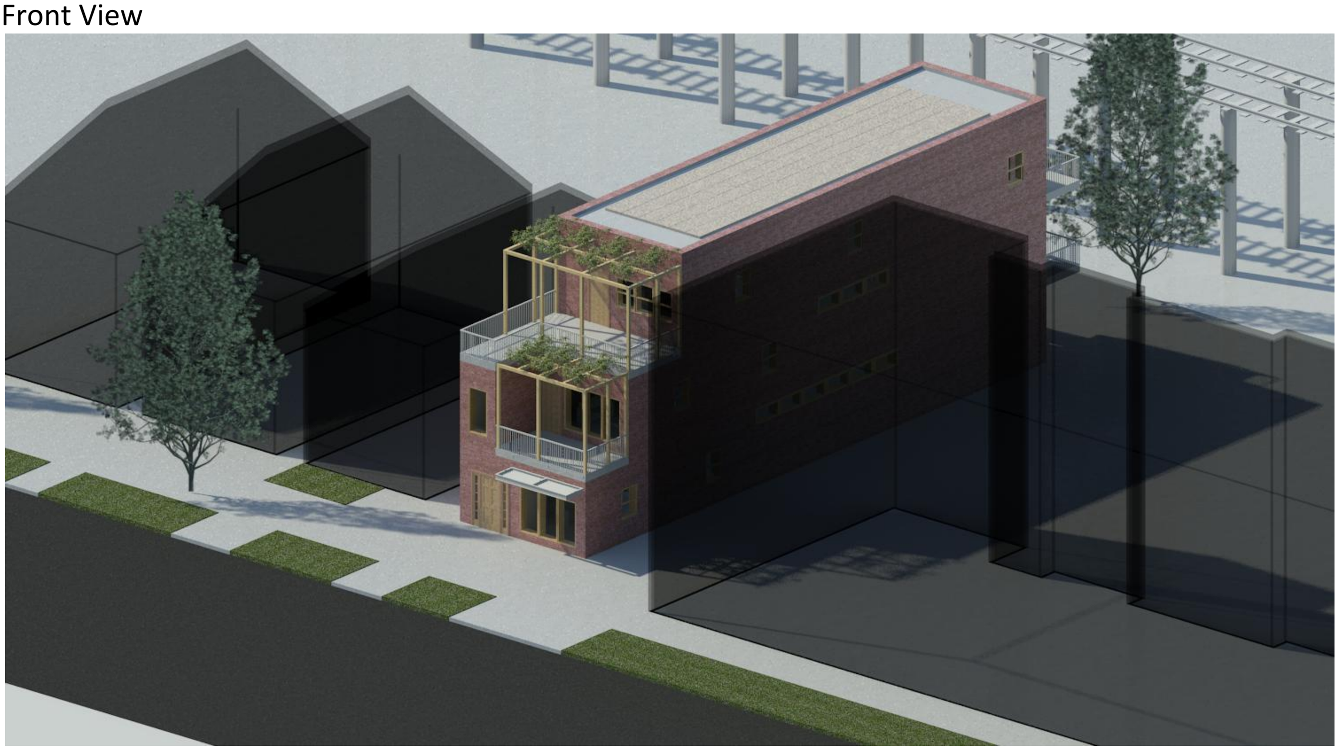
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	0.01	0.15	0.48	0.76	0.68	0.38	0.09	0.00	-	2.55
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.08	0.83	0.68	0.31	0.05	-	-	-	0.00	0.11	0.45	0.96	4.48
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.20	0.18	0.21	0.20	0.20	0.19	0.19	0.20	0.19	0.20	0.19	0.20	2.36
Vent. Fans	0.14	0.11	0.09	0.04	0.02	0.05	0.07	0.07	0.04	0.02	0.06	0.13	0.87
Pumps & Aux.	0.22	0.18	0.17	0.10	0.03	0.04	0.06	0.06	0.04	0.04	0.13	0.21	1.28
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.19	0.18	0.20	0.19	0.20	0.19	0.20	0.21	0.19	0.20	0.19	0.20	2.35
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.12	0.10	0.11	0.10	0.11	0.10	0.10	0.11	0.10	0.11	0.11	0.12	1.27
Total	1.95	1.59	1.47	0.96	0.77	1.05	1.38	1.33	0.93	0.78	1.14	1.81	15.15

Appendix 6: Final Design

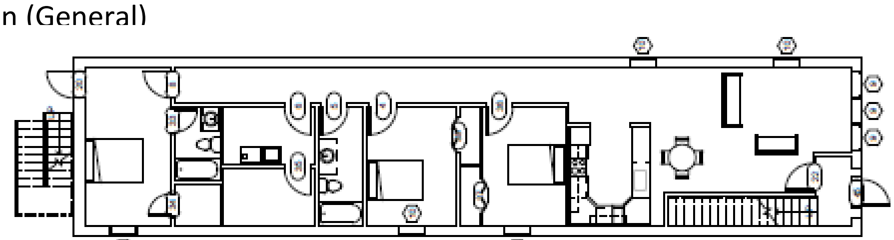
Rear view



Front View



Floor Plan (General)



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