ZERO-ENERGY INFILL HOUSING: FRONT AND BACK HOUSE OPTIONS IN MANHATTAN KANSAS

by

TRISHNA RANI PRADHAN

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Gary J. Coates

Abstract

This thesis was undertaken to investigate and seek possible architectural solutions to two issues. Firstly, fragmentation of the American family structure into a variety of new household types presents new design challenges to architects today. The single family house, once an 'ideal family' home, now needs to be redesigned to accommodate these changing lifestyles. Secondly, global warming and threats of an impending energy crisis loom large over humankind today. Environmentally-responsive architectural design can and should address both of these burgeoning problems.

A program was developed as the basis for designing new infill housing in the city of Manhattan, Kansas, a small Midwestern college town. The aim was to provide dwelling units that would accommodate a wide range of family types and use patterns of the entire life cycle while fitting in to the existing architectural fabric of the neighborhood. After a literature review, it was concluded that 'front and back house' design was the most suitable option. In this context, three types of front and back house designs are presented. These options are further divided into thirteen subtypes. It is shown that these designs fulfill the spatial needs of a variety of differing households such as houses with an office, a multigenerational home and units that permit aging in place.

An independent study was undertaken to achieve a 'zero energy threshold' for one of the designs within the design matrix presented in the thesis. A 60%-65% decrease in energy usage was attained in the front house and 50% in the back house by increasing the overall efficiency of the building envelope and by utilizing energy efficient appliances. Utilization of a 2 X 6.4 kW grid-connected solar photovoltaic system provided enough energy to power the house (inclusive of front & back houses). A Geothermal heating/cooling system was employed to further decrease the use of fossil fuel. With reduced energy needs and use of a gird connected solar system it was possible to achieve a 'net-zero energy house', which is defined as a house that generates as much as or more than the total energy it uses over the course of a year.

An economic analysis of the front and back house and proposed energy systems was also performed. Calculations suggest that rent from the back house could provide substantial financial benefits to the owner of the front house. Although use of non-conventional energy systems demanded a larger initial investment, studies showed that savings made on the utility bills would eventually help recover this investment within the lifetime of the systems.

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Acknowledgements

'I can no other answer make, but, thanks, and thanks.' William Shakespeare

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Dedication

To Bua, Mumma, Pushkar and Sailesh

Preface

'A conflict exists between the dynamic nature of people's lives and the homes in which they choose to reside. As household members grow older, their habits, lifestyles, and use of space change. Yet residents often tend to regard the physical environment in which these changes occur- the home- as unchangeable.' (Friedman 2002, p. ix)

The fact that the term 'flexible home' underlines the main purpose of this study should really come as no surprise in view of the present day housing scenario. Researchers such as Dolores Hayden (2002) & Avi Friedman (2002) believe that there needs to be more variety and flexibility of living spaces in American homes today. Studies of the American demographic patterns suggest that a home often needs to develop from its primary purpose of being a shelter to a place where people can work and conduct business. Additionally, with proper planning, a home may also serve the function of generating income for its residents. However, functionality is only one aspect of home building present day architects need to worry about. Making every bit of effort towards implementing sustainability in their designs is a responsibility that they simply cannot overlook in today's era.

In addition to a wide-ranging literature survey that was necessitated for an enhanced perception of the subject matter, two seminal works with similar objectives provided the backbone for this thesis. They laid the foundation from which the present study emerged and facilitated development of the topic by blending in the author's personal concepts. The work on *Affordable Housing* (2001) edited by professor Gary J. Coates and his students at Kansas State University and a thesis on "Zero-Energy Garage Apartment" (2008) by Harini Sarangapani at Kansas State University provided contextual support and relevant background for this thesis.

Affordable Housing (2001) conceived by professor Gary J. Coates and his students is a resourceful study that emphasizes affordable infill housing patterns in the older neighborhoods of Manhattan, Kansas. This study was undertaken after observing an increase in the housing demand in the city of Manhattan as pointed out in the *Housing*

Manhattan: Planning for the Future of July 2000 which stated the need for at least 3,000 new housing units by the year 2005. 2000 of these were required to be rental units with 950 such units meant for the lower to the middle income groups. The demographics of the city also suggested that the age group from 19-34 and 65 years and older would demand a larger share of housing. The city thus took upon itself to encourage the development of at least 70% of this housing demand or 2000 such new units (Coates 2001, p.1).

The students carrying out this research did a great deal of literature research in terms of neighborhood viability. It was concluded that the older residential neighborhood of Manhattan could support a socially diverse and denser neighborhood. These neighborhoods were at walking distances to commercial zones, educational institutes and parks thus reducing the dependence on automobiles. This locale supported both the elders as well as the younger starter couples. Another aspect of this study was to preserve the architectural character of the neighborhood.

It was concluded that such pleasing residential neighborhoods should not be transformed into the giant apartment complexes with the sole aim of maximizing population density and rental income. Rather, they could very well be developed into an owner-occupied housing that would also be affordable. The study disseminates the concept of front house-back house option that would rejuvenate the current lower densities in the housing districts. The back house could be used in a multitude of ways such as home offices, an apartment for teenagers, an apartment for the elderly parents or just as an affordable house for a starter family while generating income for the owner of the front house.

The project was designed so that it could be implemented if the current zoning ordinance was reconfigured to overlay a new district over the present city plan that would allow the construction of the *' "not-so-big" energy efficient "Front houses" (with or without light-filled, safe basement apartments) as well as loft style cottages, or "Backhouses."'* (Coates 2001, p.7) Many home owners already rent their basements to students, hence construction of such backhouses might be an equally successful arrangement. This study further states that the increasing student population and youths starting out their careers could necessitate this arrangement of the front and back house option to provide an affordable shelter to the relevant people and households. Data to support the growth in population has been described in Chapter 2 of this thesis. The products were a plethora of design solutions for the given scenario using three different neighborhoods as hypothetical sites. The economic analysis carried out test the viability of the project was most resourceful. The template used herein for the calculation has also been used in this thesis to arrive upon an economic viability of the same. This template can be seen in appendix-c of this thesis.

"Zero-Energy Garage Apartment" (2008) by Harini Sarangapani was a thesis that also had its roots in the aforementioned *Affordable Housing (2001)* by professor Gary Coates (ed.) and his students. The zero-energy backhouse was designed for a client who outlined the space needs. One of the tasks was to design a back house over the existing garage meant to be used as a rental unit while staying within the client's budget constraints. Another stated goal was to arrive upon a zero energy design so that the garage apartment would be self-sufficient with regards to its energy needs, thus bringing about the sustainability aspect into the project.

The above project highlighted the importance of lifestyle flexibility issues by making the spaces easily adaptable as required by its residents. Abundant use of the energy analysis software E10 and eQuest was made in order to achieve zero energy. Energy analysis for this thesis is guided by the analyses presented therein.

This thesis has been conceptualized to be an infill house in the older neighborhood of Manhattan, Kansas and is aimed at achieving a zero-energy design solution. The design aspect of the thesis involved a rigorous exercise to produce a matrix of design solutions aimed at catering to the issues of lifestyle flexibility. The design matrix presented is in accordance with various architectural guidelines with further improvements incorporated along the lines of present building and accessibility codes.

CHAPTER 1 - Introduction

There is no denying that global warming has been a growing cause for concern for people all around the world. Increasingly consistent data from various sources, alarming climatic changes, melting ice sheets, rising sea levels are all strong indications of this burgeoning problem. More often than not, however, the role of architects in unwittingly contributing towards this global crisis is overlooked. By making an astute choice of construction materials and developing innovative means of utilizing natural resources, architects can make a huge impact in the global scenario by designing buildings that remain environmentally friendly throughout their lifetimes.

This thesis delves into the study of two major subjects –*American Lifestyle Diversity* and *Global Environmental Issues* in the form of multi-faceted tribulations that the world faces today in the form of Global Warming and the impending Energy Crisis. The aim is to arrive upon an architectural solution that not only ensures lifestyle flexibility but also proactively addresses issues related to the energy crisis and global warming.

This Chapter is divided into three sections:

i) The first section describes the literature on the American Life Cycle Study.

ii) The second section describes the Global Environmental Issues.

iii) The third section discusses the aim, methodology and limitations of the thesis.

iv) The third section outlines the Chapters of this thesis.

American Life Cycle Study

"To renew democratic, self-sufficient traditions and survive as an urbanized, modern society, Americans must search for an adequate way to organize and pay for the spaces we live in, a way more compatible with the human life-cycle." - John Demos (Hayden 2002, p.77)

The development of the modern American household – the change from the notion of a male breadwinner and his spouse, the homemaker, to present times where both parents contribute equally towards the household income has been amply documented in a variety of texts. According to the book, *Redesigning the American Dream* (2002) by Dolores Hayden, only a very small fraction of the American households had a *'male breadwinner, a nonemployed housewife, and children under eighteen'* in the year 2002 (Hayden 2002, p.59). She adds that married couples with children under the age of eighteen constitute one fourth of the households with 29.2% of such households having a male as a sole breadwinner.

The author intends to divulge that today most of the families are of the *'two-earner'* type, where both the husband and wife work. Additionally, in this book she also recognizes single parent family as a rapidly growing family type with five out of six such families headed by women. She adds that more than a quarter of all households consist of single people living alone (Hayden, 2002, p.59). Hence a typical family is fragmenting into a variety of households so it is imperative to widen the architectural design program to accommodate the needs of such a variety.

It was understood from Dolores Hayden's study that *'single family dream house'* was being torn down in many cities such as Springdale, Connecticut to give way to apartments where the various floors could be leased out to help pay high property taxes. Many single family houses were being remodeled into apartments when it was difficult to sell them. Hence in case of divorce, relocation or retirement such an arrangement made sense as the rental income could be used accordingly (Hayden 2002, p.193-195).

Dolores Hayden states that per capita housing space in America is largest in comparison to any other country. The research states that many elderly seek to live in smaller units and even youngsters look for smaller homes that can be easily managed (Hayden 2002, p.193-195).

This literature study also revealed that there was a growing need for houses conducive towards working from home. Women were now taking an active part in household income generation and most of them preferred to work from home as freelance writers, graphic designers, architects, typists and the like. A contemporary design would therefore need to accommodate these varied expectations and requirements.

Accessory apartments such as garage apartments and backhouses are also advocated by Dolores Hayden as they accommodate the growing needs of the families. The author uses the research of Patrick Hare who identifies seven constituencies supporting such accessory units. The following is an excerpt from her book describing the same:

1. *'Many socialists have observed that the elderly do not choose to move out from their homes, even when their health or financial situation becomes precarious. Many elderly cannot bear the psychological consequences of losing ties to their dwellings and communities. In addition, many elderly in good health may want accessory apartments either for income or for tenants who could help with some home maintenance.*
2. *A second constituency for change consists of young people who are now tenants of apartments and their middle aged parents who are owners. Many young single people and young childless couples cannot afford to buy homes in the town they grew up. They would like to be near their children and help them economically. In the past, the parents might have provided their children with the down payment on small house near their own; now all they can provide is an accessory apartment in their own home.*
3. *The potential for such accessory apartments exists for single parents, male or female and their children.*
4. *Women form a fourth constituency. Women often bear the burden of maintaining kinship ties across generations.*

5. *A fifth community consists of environmental activists. In such an effort, conservation- minded citizens and small designers, carpenters, and builders might find common interest.*
6. *The sixth constituency is people of color, both owners and renters, who have experienced difficulties in finding, renting, buying, and reselling suburban dwellings.*
7. *A seventh potential constituency consists of the people, who cannot stand noise, too many cars, or greedy neighbors.'* (Hayden 2002, p. 201- 204)

Sarah Susanka, in her book *The Not So Big House* (1998)**,** outlines the importance of having a house that has quality in its spaces rather than quantity. She advocates a functional house that has spaces which can be used everyday rather than a house that is huge and mostly out of use. She says that the house should nurture its inhabitants rather than impress them and, therefore, a house need not be a castle. This is an important point to be noted since a lot of resources are wasted in building houses that are very big. After the children move out, parents often find that the house quickly becomes an expensive commodity to maintain while also being underutilized. Therefore, in order to cater to an American family of the 21st century the author presents a case study of the 'Not So Big House' that adequately provides for their complex lifestyles while striking an astute balance between grandeur and functionality. However, some of the houses that she describes in her book are large homes where the cost of such houses may become an issue.

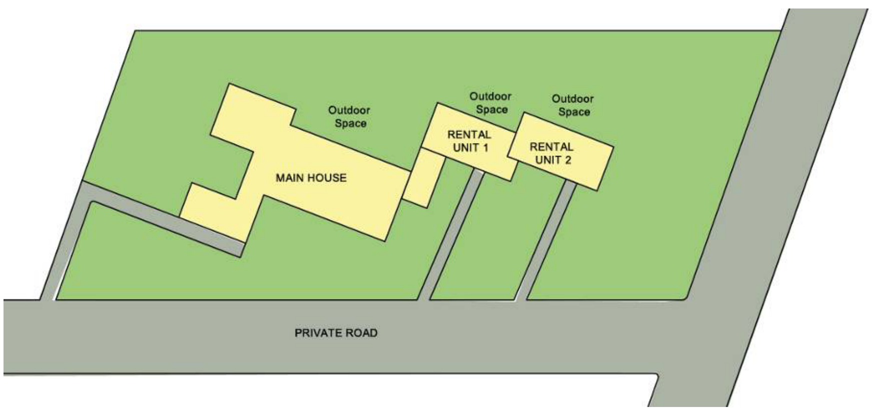
Julius Ralph Davidson's "Case Study House#1" (p. 42) in the *Blueprints for Modern Living* (1989) is an excellent example of the dynamic lifestyle flexible house meant for an American household. He builds a case study wherein he supposes that it is a two- earner household, with a teenage daughter and an elderly mother-in-law who occasionally visits the house.

Among the various aspects in the design, he accommodated a separate entrance into the suite for the teenage daughter or a visiting mother-in-law. This feature illustrates an important aspect of flexible design where the daughter and the in-law are both given the freedom to maintain their own lifestyles outside the house while still living within the protective envelope of the same house.

The addition of two rental units adjoining the house helps in planning for the future where the rental units can add to the income of the owners. These rental units were designed keeping in mind the privacy required between the various households. This arrangement creates a micro-environment within the site of the house that shows the changes in the social as well as the economic needs of families today. This house went into construction for a family who enjoyed the ample storage that had been provided in the house. The plans of the house have been documented in Fig. 1.1 and Fig 1.2.

Figure1.1 Site Plan of the Case Study House

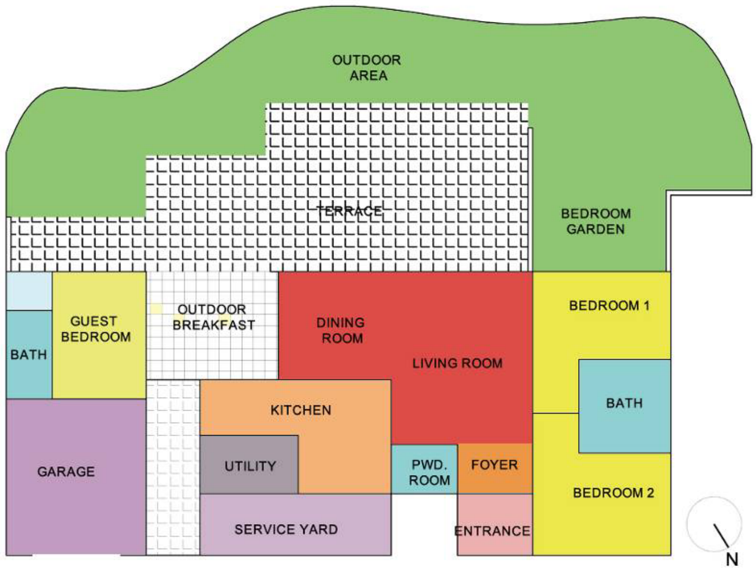
(Adapted from *Blueprints for Modern Living* (1989, p.42))



The site plan shows the main house and the rental units. Separate entrances to the different houses from the street as well as orientation of the houses ensure privacy.

Figure 1.2 First Floor Plan of the Case Study House

(Adapted from *Blueprints for Modern Living* (1989, p.42))



The first floor plan of the house shows how the guest room is segregated from the main house ensuring privacy and freedom when occupied by an in-law or a teenage child. The plan also use of passive solar heating technique wherein most of the outdoor and living area faces the south.

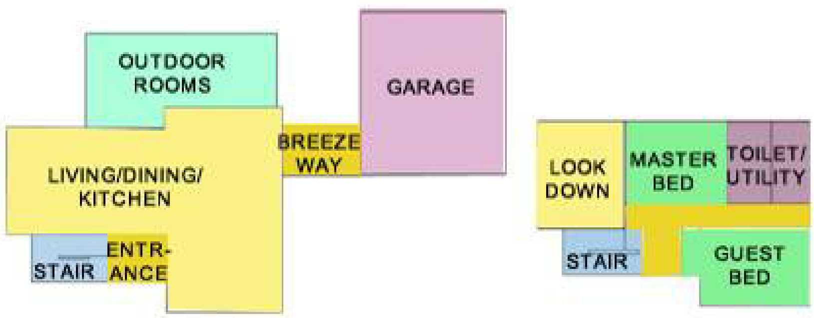
The demands of the modern American lifestyle are well encapsulated in a design solution presented in “A Home for all Stages” by Lisa Gaddy Frederick in *Better Homes and Gardens* (2005). This dwelling was conceptualized as a house which would support living and the idea of aging in place was highlighted. The design depicted the various phases in which a house could be built and/or remodeled, first accommodating the needs of a young starter-couple and then unfolding into a bigger house to accommodate the growing family with spaces carved out for home occupations. Finally, phase three gives an option for couples who want to age in place converting the office into a smaller bedroom and a laundry room. This room could also be used by an elder parent who wants to avoid climbing cumbersome stairs.

This project was very helpful as it graphically represented what was being preached by many such as Dolores Hayden, Sarah Susanka and Julius Ralph Davidson. It helped in outlining the research as regards to the space requirements and the flexibility that needed to be incorporated into the design of a house for a contemporary family. The design agrees with Sarah Susanka's concepts of the *Not So Big House* (1998) in stating, that instead of wasting spaces, only those that are required in a household should be provided. The openness in plan helps to connect the families while occupying different sections of the room. The images of the adapted plans have been provided below:

Figure 1.3 Adaptive House

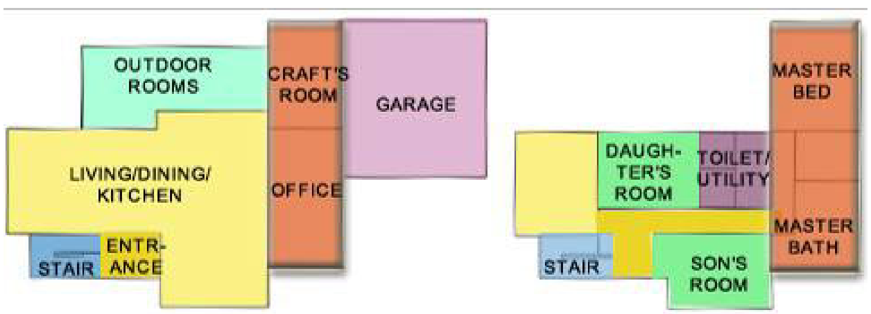
(Adapted from *Better Homes and Gardens* (Nov. 2005, p.192 &195))

Phase I Home: Is designed as a home for young or starter couple without children.



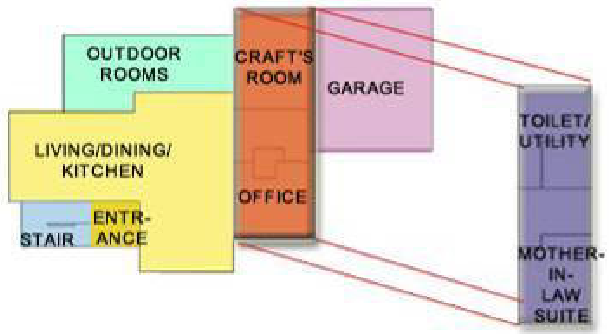
First Floor   Second Floor

Phase II Home: As the family grows, new rooms are added in the first and second floor utilizing the space in the breezeway existing in phase I home.



First Floor   Second Floor

Phase III Home: exemplifies the scenario of multigenerational home where an aging parent moves into the house. The craft's room in the first floor is remodeled to accommodate the parent.

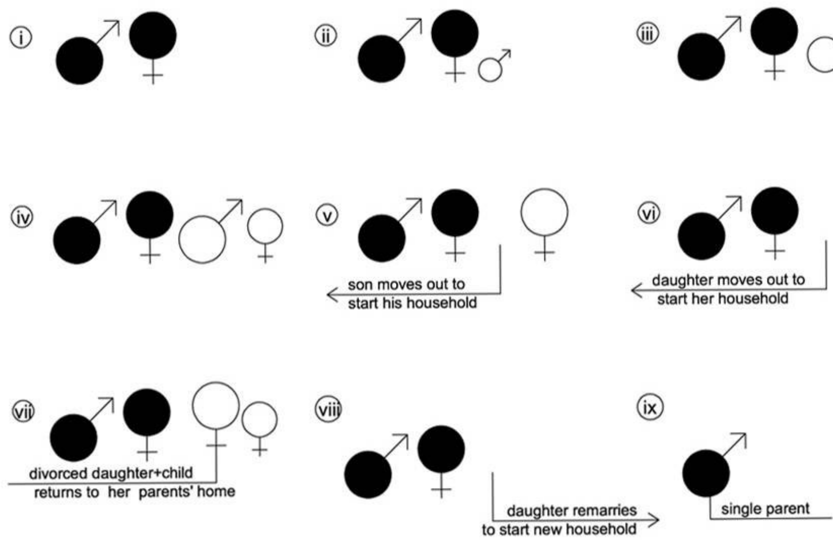


First Floor Remodeled space

Avi Friedman, in his work *The Adaptable House* (2002), puts forth his principles in designing a house that could easily adapt to the changing needs of the residents. *The Adaptable House* discusses the fact that many homes are very rigid and do not allow flexibility in the changing needs of its residents. The writer brings forth the fact that a *'typical North American wood- frame home'* (Friedman 2002, p. x) provides shelter to eight different homeowners throughout its lifetime. Therefore, the house should be able to accommodate the needs of different homeowners. The author cleverly describes the present day lifestyle of a typical American household and illustrates the importance of design of a house in answering to the needs of its residents. One such household pattern is presented below.

Figure 1.4 Graphical Representation of a Typical American Household Scenario

(Adapted from – Friedman 2002, p. 6)



The study of a wide array of literature certainly helped in outlining the design aspect of this thesis. It is not easy to make predictions on the future patterns of the American families. Even so, a designer can introduce flexibility in his or her design. A flexible house will allow for minimal remodeling while accommodating changes in the household. This will ultimately enable the owner to own the house for a longer duration. The study also provided evidence that an accessory apartment was a bonus in the twenty-first century scenario where one needs financial stability especially after retirement. The accessory apartment is a blessing for not only does it help in income generation for the household but also accommodates additional members of a family should they choose to stay there.

These concepts, discovered through the literature study, were used in this thesis to design a house that could satisfy the changing spatial requirements of its owner through his or her life. Hence this study on lifestyle flexibility assisted in the design process which will be divulged in the Chapters to come.

A home is a place that nurtures the people who inhabit it and at the same time it should have the potential to adapt to the changing lifestyle of its people.

"A house will continue to mirror the tastes, habits and lifestyle of the people who inhabit them…" (Friedman 2002, p.2)

Global Environmental Issues

During the post Industrial Revolution period, there was major technological advancement, population explosion and high demand for natural resources accompanied closely by an increase in pollution. Fossil fuel (oil & gas) used affects the environment in myriad ways including the production of CO_2 which we today know contributes adversely to global climate change. Given the rate at which we are extracting and using oil and gas, studies by scientists indicate that energy crisis will start becoming prominent as early as the year 2012 (Bartsh and Muller, 2000).

Twenty one percent of carbon dioxide is emitted by the residential sector in the USA (LEED 2007, 1.11a: 4). According to the U.S Department of Energy, buildings use 37% of the energy and 68% of the electricity produced in the USA (LEED 2005, 2.2:149). A typical building's energy bills constitute 25% of the building's total operating costs. Buildings contribute to 48% of the total greenhouse gas emissions in the USA annually (http://www.architecture2030.org/home.html:8/25/'08).

According to *LEED for Homes Program* (LEED 2007, 1.11a:4), there are about 120 million homes in the United States with 2 million homes being added each year. The residential sector consumes nearly 22% of the annual energy produced in the USA and up to 74% of water and the quality of the indoor air is worse than the outdoor air (LEED 2007, 1.11: 4).

Today's issues of global warming, the energy-crisis and consequently the sky-rocketing energy costs, call for architecture that is not only aesthetically sound but also environmental friendly. *Architecture 2030*, which is a non-profit organization, works towards an architecture that is amicable to the environment. It was established in response to the *global- warming crisis*. The Mission Statement of this organization is to use buildings as a means to solving the current global- warming crisis, rather than simply allowing buildings to be a major source of the same. The organization intends to reduce the emission of hazardous green house gases through necessary changes in '*planning, design, construction'* of buildings.

The organization has put forward its *2030 Challenge* that aims at reducing the consumption of fossil fuel and Green House Gas emission by *50%* by *2010*, and making the buildings *carbon neutral* by *2030*. The idea is to slow down the emission of the harmful green house gases and then reverse this emission in 10 years so that the global warming can be kept *'under one degree centigrade above today's level'*.

The 2030 Challenge target is outlined below:

- *'All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type.*
- *At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, Green House Gas-emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type.*
- *The fossil fuel reduction standard for all new buildings shall be increased to:*

60% in 2010
70% in 2015
80% in 2020
90% in 2025
Carbon-neutral in 2030 (using no fossil fuel GHG emitting energy to operate).

These targets may be accomplished by implementing innovative sustainable design strategies, generating on-site renewable power and/or purchasing renewable energy and/or certified renewable energy credits.'(http://www.architecture 2030. org/ 2030_challenge/index.html: 2/24/'08)

Recent works in architecture such as 'green design', zero-energy architecture and the like, are trying to mollify the effects of global warming and the energy crisis. Such works are trying to achieve the 2030 challenge discussed above.

Given the imminent global crisis, a new movement in architecture, termed *green building* and *green design*, is taking on the construction markets. Green Design is a difficult term to define and can have many meanings depending on the context. *LEED for Homes Program* (2007, 1.11a:4) points out the following qualities that a Green Home should have:

- *'Higher performance levels than conventional homes'* that follow minimum building codes.

- Green Homes are '*healthier', 'comfortable', 'durable'* and *'energy- efficient'.*
- These type of homes have a smaller *'environmental- footprint'* than conventional homes.
- Green Homes use established design features and technologies that are not very expensive.
- Many green measures reduce long term costs such as those pertaining to energy and water use. These reductions in utility costs often surpass the initial upfront cost of green homes. (LEED 2007, 1.11a: 4)

Zero Energy Architecture is another fertile area of development in the movement towards sustainability. A house with a *'net energy consumption of zero over a typical year'* is called a Zero Energy House. Energy can be measured using three factors - carbon emission, energy or cost. The definitions do not take into account the *embodied energy* in the structure or the amount of energy used in construction of the project leading to a positive amount of carbon emissions.
(http://www.solartoday.org/2005/may_june05/ZEH.htm: 4/24/'08)

For the purpose of this research the following definition for zero energy architecture is used: *Energy consumed= Energy produced* over a typical year.
If the total amount of energy used to operate the house (heating/ cooling/ ventilation/ lighting) and appliances is equal to the total amount of energy produced by the house then it can be called a Zero Energy house.

The objectives set forth in Green Design and Zero Energy architecture are not impossible to obtain. As responsible architects it is important to meet both the space needs as well as the cry for an environmentally sound architecture.

This thesis uses the concepts of Green Design and Zero Energy Architecture to make the designed house more sustainable. Emphasis has been placed on reducing the energy consumption of the house by a combination of design features and the generation of renewable energy on-site. These strategies will be discussed further in the thesis.

Thesis Aim

Studies conducted on the two aspects – lifestyle flexibility and global environmental issues – which form the basis of this thesis, were immensely helpful in defining its objectives. While demographics suggest that a house needed to be more flexible to accommodate the lifestyle of its residents, lurking issues of global warming and energy crises demanded the need to implement means to curtail global warming along with the use of alternate renewable energy systems. These conclusions were further bolstered by the fact that houses used 68% of the electricity and 37% of the energy in the US, according to a study conducted by the U.S Department of Energy (LEED 2005, 2.2:149). It was, therefore, deemed imperative to address both the above issues while arriving at a viable architectural solution. Consequently, the aim of the thesis was defined as follows:

To design a house that caters to lifestyle flexibility and space needs of the 21st Century American family, employing strategies to achieve a zero energy housing solution that can verily function as a power house in itself: self- sufficient as regards its energy needs.

To achieve the aim stated above, lifestyle flexibility issues were addressed by adopting the front-house back-house option, as presented in *Affordable Housing* (2001) edited by professor Gary J. Coates. The front house was part-owner occupied and part-leased with some variants, while the back house is designed to always be a rental unit benefiting the owner of the front house as an additional income source. The incorporation of diverse social and architectural aspects helped in arriving at a matrix of design solutions that meet the needs of a variety of American households. Further analysis of the matrix utilizing the template of Building Codes and the American Disabilities Act helped in upgrading the design matrix to a practical design solution.

The energy aspect of the analysis was tackled by following the basic principles of bioclimatic architecture, increasing the air tightness of the building envelope, adopting passive heating and cooling strategies together with energy modeling tools and use of renewable energy systems. The energy analysis part of the design was accomplished as an independent research initiative.

Methodology and Limitations

The thesis is subdivided into four major categories with set goals in order to achieve the proposed zero energy infill housing solution.

Since there was no client available at the time this thesis was drafted to define the parameters for this project, the first goal was to identify the same for a hypothetical design site. Scanning numerous local home-design magazines helped to choose the types of spaces to be incorporated into the proposed design. Another important aspect was a context study that needed to be addressed to build a case and make the proposed design a part of the chosen locale. To this end, the principles of New Urbanism were profusely used together with the local precedents and the present housing demand in the city of Manhattan, Kansas. This portion of the thesis involved qualitative analysis.

The second and critical goal was conceptualization of the actual architectural design scheme for a house that would reflect lifecycle changes. This, like any other design exercise, was achieved through constant reconfiguration of plans, elevations, sections and views in order to fully manifest the idea. Bioregional design strategies along with zoning and building codes, ADA standards, graphic and visual codes provided a helpful framework within which to achieve the design. Finally, a matrix of design solutions was formulated that could be accommodated in the chosen hypothetical site. Qualitative analysis was involved in this section as well.

The third goal was the realization of zero energy design. In order to achieve this, an independent research was carried out within the framework of the graduate curriculum. One of the designs from the matrix (1a) was chosen to be taken a step further so that the whole configuration could be made as energy efficient as possible. Both passive heating and cooling design techniques coupled with modern day simulation software were engaged in the energy analysis of the design. Renewable energy systems namely, a photovoltaic system, a geothermal heat pump and a solar water heater, were harnessed to achieve energy self- sufficiency with a grid connected system for backup in case of continuous cloudy days, thus achieving a zero energy design. The cost of the systems was also calculated. Energy efficient appliances that could invariably reduce energy consumption were identified.

Finally, an economic analysis was carried out to understand the economic viability of the project in the given context. This was a quantitative analysis that involved construction cost analysis of the building envelope as well as the analysis of the amount of capital required for initial investment to build the house, the mortgage, the interest, the cost of maintenance and finally the net gains from the apartments that were to be leased out. Economic viability and the return on investments of the renewable energy systems were also calculated. To simplify the procedure, the design that was upgraded to a zero energy design was used for the economic analysis.

The thesis entitled “Zero-Energy Garage Apartment” (2008), by Harini Sarangapani at Kansas State University, provided an in-depth study of the green materials that could be used in Manhattan, Kansas. The same materials were chosen for the purpose of this thesis thus avoiding any further material research. The materials used are only reflected during the construction cost analysis and this may be identified as a limitation of the current project.

Thesis Chapter Outline

This thesis is presented in six parts comprised of an introduction followed by five Chapters. The Introduction mainly includes an overview of the two aspects being researched in the thesis namely, changes in *American Lifestyle* and *Global Environmental Issues;* this Chapter also discusses the aim of the thesis.

Chapter 2- Pre-design: this Chapter is comprised of a context study that weaves together the larger picture of the global issues within the framework of the housing needs of the City of Manhattan. Local precedents are presented and a variety of issues related to neighborhood infill in the city of Manhattan are also discussed. The site for the design is also described in this Chapter.

Chapter 3- Design: this Chapter shows how the city zoning, building codes, visual analysis and architectural guidelines are used to create a context for the design of a matrix of design solutions that cater to different lifestyles and stages in the life cycle. A narrative describing each group in the design matrix is also provided. Design documentation, including plans, elevations, sections and perspectives for all the designs formulated in the matrix have are given in this Chapter.

Chapter 4- Energy Analysis: Energy analysis for one of the designs from the larger matrix is summarized in this Chapter. A brief description of the software used for calculating energy needs of the house is also given. The changes needed to be carried out in terms of plan/elevations in order to achieve zero energy design are described in this Chapter. Finally the renewable energy systems proposed to be used to achieve zero energy design are presented here.

Chapter 5- Economic Analysis- A comprehensive calculation of construction costs, net gains from rents and the cost of maintenance is summarized. Calculation of the total profit from the house and the rental unit to arrive upon the economic viability of the project is given in this Chapter. This Chapter also focuses on energy economics to understand the economic gains and tradeoffs for using renewable systems.

Chapter 6- Conclusion: This Chapter provides an overall summary of the project addressing both the demographic aspect as well as the energy efficiency achieved.

Identification of the limitations and shortcomings of the project as well as the scope for future study on the project are also discussed.

Appendix: Is composed of additional information on the project and various calculations involved. This section also holds many of the detailed designs of the various house types presented in the matrix. The graphs produced during the energy analysis are also provided in this section of the thesis.

CHAPTER 2 - Pre-Design

"When we build, let us think that we build forever." John Ruskin

The thesis was conceptualized as a feasibility study for an architectural design incorporating relevant findings from studies pertaining to lifestyle flexibility and global environmental issues. The design was created such that it may readily be implemented in the construction of new structures if the City of Manhattan were to re-configure its zoning scheme to allow for the proposed configuration. The project is documented along the lines of many architectural research works that transpire from the study of site and surroundings, culminating in a suitable architectural design.

This Chapter discusses the study of the site and context and is presented in two sections.

1) **Manhattan, KS**: geographical, climatic, demographic and social description of the location, reasons for the choice of the lot for the proposed design and design challenges presented by the site.
2) **Context study**: weaving the larger picture of the global issues within the framework of the City of Manhattan, building a *case* for the study to be a potential solution for the housing demand in Manhattan, Kansas.

Manhattan, Kansas

Manhattan, Kansas was selected as the location for the design, since it was planned in the grid-iron pattern which is ubiquitous in most American cities. Moreover, ample data about the area is readily available. Kansa Indians were the first known inhabitants of Manhattan; it later became the home to settlers from the Eastern territories of New England and Cincinnati, Ohio (Briscoe 1979). Thirty percent of the residents had German origin and 11% have roots in Ireland (http://www.epodunk.com: 04/25/'07). The land near the Big Blue River was found to be fertile and hence this land was chosen for agriculture.

The town was laid out in a grid pattern by the early settlers. Consequently, side streets were 60 feet wide and every other seventh street or avenue was 100 feet across. It was decided that the broader streets would have double rows of trees. Gradually it grew from a small agricultural town into a thriving University town. The close proximity of Fort Riley which is a United States Army post, adds to the importance and popularity of this city. Manhattan, Kansas was recently rated as one of the ten best places in the USA to retire young (http://money.cnn.com/galleries/2007/moneymag /0703/gallery. bp_ retireyoung_new.moneymag/9.html: 3/11/2008).

Geography

The geographic coordinates of Manhattan are latitude 39°11.5′ N and longitude 96°35.5′W (http://www.city-data.com/city/Manhattan-Kansas.html: 3/11/'08). The Kansas River serves as one of the boundaries to the city. According to the United States Census Bureau Manhattan has a total land area of 15 square miles (http://www.ci.manhattan.ks.us: 3/11/'08). It is located in the Flint Hills with grasslands reaching out to horizon covered by an open sky dome.

Climate

Since Manhattan lies in the path of the cold polar air and the warm air from the Gulf of Mexico it has a high risk of tornadoes due to the mixing of the aforesaid hot and cold air. It is a well known fact that Kansas is one of the states that lies in the 'Tornado Alley'. (http://whyfiles.org/013tornado/2.html: 3/11/2008) Manhattan has very unpredictable weather so it is not unusual to have a perfect sunny morning marred by thick cumulus clouds in the evening. The climatic data provided below states that the average extreme temperature ranges from 15°F in January to 93°F in July. A temperature of nearly 90°F is observed for 56 days annually while there are almost 9 hot days with temperature attaining a high of 100°F; the city has 118 days of below freezing temperatures. Manhattan receives about 35 inches of precipitation in the months of May and June. The annual rainfall ranges from 24-46 inches with around 97 days of measurable rainfall in a year. The snowfall depth averages almost 16 inches with around 10 days of measurable snowfall; there are 20 days yearly when the snow depth is just about an inch (http://www4.ncdc.noaa.gov: 3/11/2008). A comprehensive climatic data for Manhattan is provided in Table 2.1. This data provides evidence about the extreme temperature swings in Manhattan, with the lowest temperature of -37° F and highest temperature of 116 °F.

Table 2.1 Climatic Data for Manhattan Kansas

(Source http://www4.ncdc.noaa.gov: 3/11/'08)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temp. (F)													
Mean high	39.5	46.8	57.5	67.9	77.5	87.1	92.5	90.8	82.1	70.7	54.5	42.9	67.5
Mean low	16.1	21.5	31.4	42.2	52.5	62.3	67.3	65.1	55.5	43.2	30.2	19.9	42.3
Highest recorded	74 (1939)	84 (1972)	95 (1907)	99 (1910)	103 (1934)	112 (1911)	115 (1936)	116 (1936)	112 (1947)	98 (1947)	87 (1909)	77 (1939)	116 (1936)
Lowest recorded	- 31 (1947)	- 26 (1905)	- 12 (1948)	5 (1920)	23 (1907)	39 (1946)	38 (1902)	40 (1916)	26 (1995)	13 (1993)	- 9 (1952)	- 22 (1989)	- 31 (1947)
Precipitation (inches)													
Median	0.79	0.92	2.11	2.22	4.53	4.62	3.2	2.93	3.28	2.38	1.51	0.85	34.34
Mean no. of days	5.4	5.2	7.9	10	12	10.9	8.6	9.2	8.1	7.7	7	5.2	97.2
Highest monthly	3.16 (1979)	2.48 (1997)	7.40 (1973)	9.52 (1999)	14.73 (1995)	11.55 (1977)	17.56 (1993)	7.25 (1977)	9.89 (1973)	6.49 (1973)	5.79 (1998)	3.40 (1973)	
Snowfall (inches)													
Median	3.7	3.2	0.8	0	0	0	0	0	0	0	0.1	1.7	9.5
Mean no. of days	4.5	3.2	1.7	0.6	0	0	0	0	0	0	1.5	3.5	15
Highest monthly	16.2 (1985)	18.5 (1978)	9.0 (1998)	4.8 (1975)	0	0	0	0	0	1.1 (1991)	8.8 (1975)	14.6 (1983)	

Mean and Averages were calculated for 30 year period 1971-2000 and temperatures were taken from the station records between 1900-2001. The station is at an elevation of 1065 feet.

Demographics

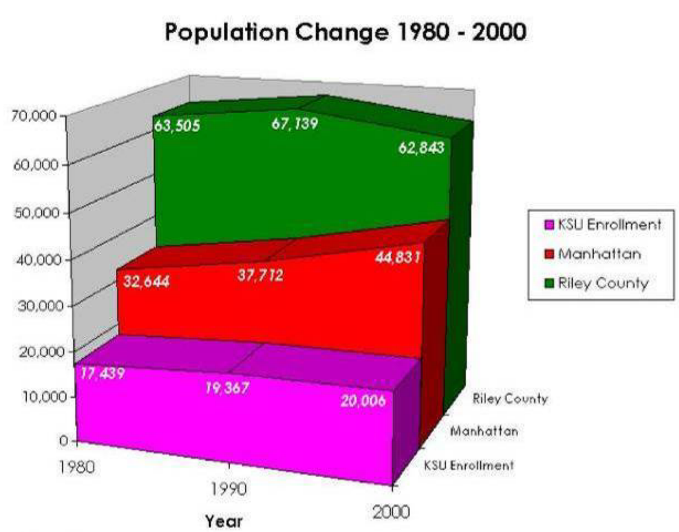
According to the 2000 census there were 44,831 people in Manhattan with 23,107 males and 21, 724 females. The number of people below 5 years of age was 2,083 and 583 people were 85+ in age. The median age of the city was 23.5 years. The average family household size was 2.34 and the size of an average family was 2.89. (http://censtats.census.gov/data/KS/1602044250.pdf: 3/11/'08)

As of 2000, the total number of households was 16,949 with the housing density of 1177.4/ sq mi. 22.7% of the households had children below the age of 18, 39.6% comprised of married couples living together and 6.6% were headed by single female householders without a husband and 51.3% were single. It was also recorded that 30.5% of the population lived alone and the percentage of people 65 years and older living by themselves was 6.3%. Forty percent of the population belonged to the age group 18-24 which is a common phenomenon in a university town.
(http://factfinder.census.gov/home/saff/main.html?_lang=en: 3/11/'08)

Figure 2.1 shows this population increase where one can observe the contribution of the increasing student population to this. This Figure provides evidence of the fact that Manhattan, Kansas is a growing town where the population has increased by 12,189 from 1980-2000.

Figure 2.1 Population Change from 1980-2000

(Source: http://www.ci.manhattan.ks.us/DocumentView.asp?DID=2597: 3/11/'08)



The distribution of races in the city was as follows: white non-Hispanic (85.4%), black (4.9%), Hispanic (3.5%), two or more races (2.1%), Chinese (1.4%), other race (1.3%), American Indian (1.0%), Asian Indian (0.9%), Korean (0.7%). The estimated population by the year 2006 was projected to be 50,737 (http://www.city-data.com/city/Manhattan-Kansas.html : 3/11/'08).

Economic Data

In 2000, the mean income of a family was $30,463 and the per-capita income was $16,566. The males earned $31,396 and female full-timers received $24,611. The mean retirement income of an individual was $17,855 (http://censtats.census.gov/data/ KS: 3/11/08). Table 2.2 shows the household income from 1999-2000. The median income has increased from $21,531 in 1990 to $61, 520 in 2005. This data is especially helpful during the economic analysis that is presented in Chapter 5 of this thesis.

Table 2.2 Household Income in 1990- 2005

(Source**:** http://www.ci.manhattan.ks.us/DocumentView.asp?DID=727: 8/28/'08)

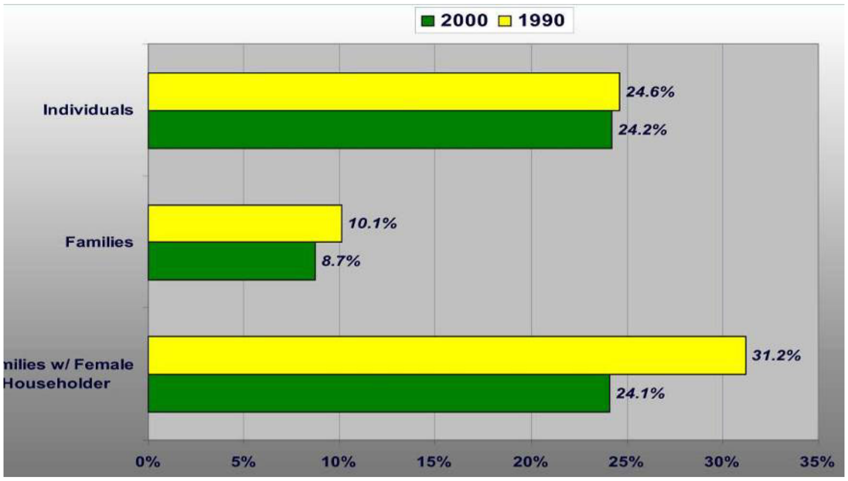
Income Group	Less than $10,000	$10,000-24,999	$25,000-34,999	$35,000-49,000	$50,000 and Over	Total	Median Income
1990	24.5%	22.4%	23.3%	13.9%	15.9%	100%	$21,531
2000	19.3%	18.3%	28.4%	16.9%	17.0%	100%	$42,800
2005	15.5%	14.3%	31.5%	18.8%	19.9%	100%	$61,520

According to the census in 2000, 8.7% of families and 24.2% of the population were below poverty line along with 10.1% of the population below 18 years and 7.8% over 65 years falling in this category (http://factfinder.census.gov/home/saff/main.html?lang=en: 3/11/08). Figure 2.2 shows the poverty status in the city.

The demographic data shows that 6.6% of the households are headed by women. The data in the Figure proves that this household sector is worst struck by poverty in comparison to individuals and other households. The fact that households headed by single women usually live below the poverty line is also pointed out by Dolores Hayden in her book on *Redesigning the American Dream* (2002).

Figure 2.2 Poverty Status 1999-2000

(Source: http://www.ci.manhattan.ks.us/DocumentView.asp?DID=2598: 3/11/'08)

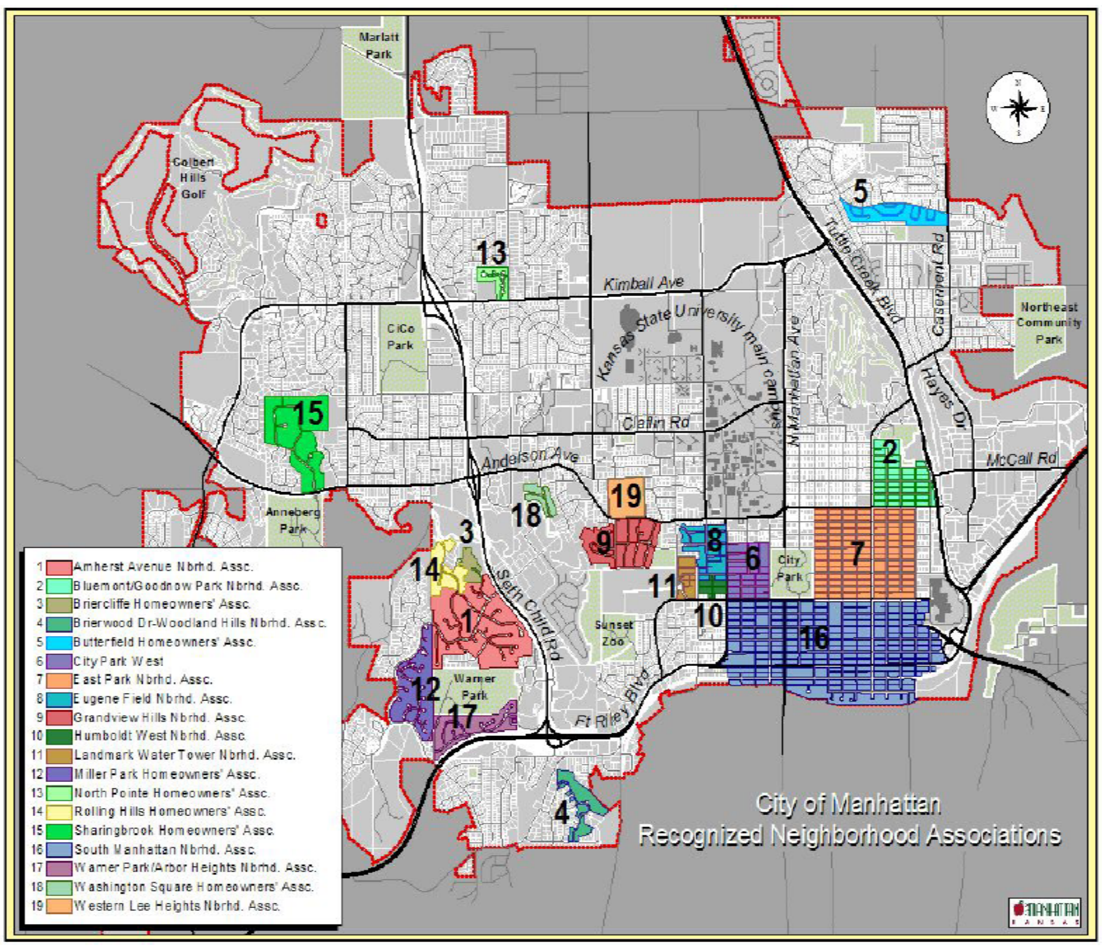


The Site

It was vital for the purpose of this thesis to select a suitable site in order to illustrate the feasibility of the design solution in a real-life scenario. Since the thesis was an infill housing option in the older residential district of Manhattan, a vacant lot in the vicinity of such a neighborhood would serve as a perfect hypothetical site. A major task was to identify one such lot in the older residential neighborhood. The map provided in Figure 2.3 represents the residential neighborhoods of the City of Manhattan.

Figure 2.3 Residential Neighborhood Map

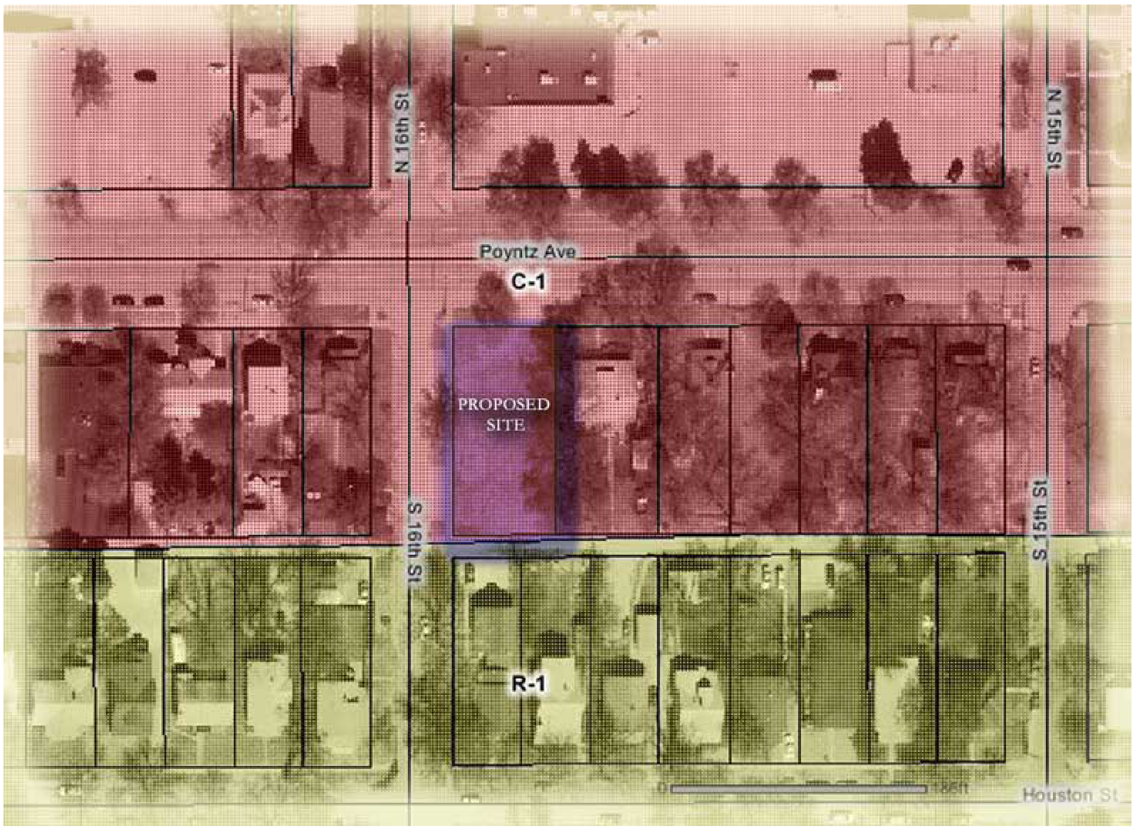
(Source:http://www.ci.manhattan.ks.us/common/modules/documentcenter2/documentview.asp?DID=1650 : 04/15/'07**)**



An unoccupied lot located at the intersection of Poyntz and S 16th Street was spotted. The vacant lot chosen was at the north-east corner of the intersection of the two arterial roads in the city.

Figure 2.4 Site for Zero Energy Infill House

(Source: http://gis.rileycountyks.gov/website/rileyco/viewer.htm:04/15/'07**)**



The site was in the C-1 (restricted commercial) zone, and after correspondence with the Planning Office at Manhattan, it was understood that a *conditional use permit* could be obtained for the given site; it also qualified to be used for purposes permissible in the R-3 zone. The R-3 zone is a district in the city that is permitted for developing Multi-Family residences. The site is located in a neighborhood with a low density which can be seen in Figure 2.4 above. Hence, an infill house with an accessory apartment was deemed a viable option for the location as the site is located in the older residential locale of Manhattan where multi family residential development was permitted.

The location of the plot on Poyntz Street was an added advantage since it is one of the major streets in the city. Poyntz was the street that decades ago divided the holdings of the New England settlers from the Ohio settlers. Since the site was a corner lot, the architecture built on it would have urban visual responsibilities since corner lots add to the character of the city or the block. According to the book *Responsive Environment* (Bentley et al. 1985), *legibility* and *visibility* are two of the six important characteristics of a responsive urban environment, and city corner lots have much to do with this. The corner lots give a character to the two streets abutting it and hence to the urban environment. City landmarks built in corner lots help orient visitors as well as the denizens of the city. This lot could also be developed as one that could assign a character to the two roads next to it and the block.

The north of this property faces Poyntz Avenue and the Arts' Center thus looking on to a public realm. The east edge has a row of trees curtaining it off from the residences adjoining it. The south end of the site faces ordinary residences and its west faces S16th Street. Hence the structure built on this site could give identity and personality to the area since the architectural character is not yet defined in this block. Apart from its utilitarian purposes, the rear alley could be developed as the entrance to the accessory apartment rendering a distinct character of a rear streetscape. This would give the site three facades, one looking towards Poyntz, the other towards S16th Street and the last looking towards the alley. Conservation of visual character of the residential neighborhood was also a vital consideration in the design. Figure 2.5 shows pictures of the site and its surrounding.

Figure 2.5 Photographs of the Site

The Block   Looking towards Poyntz

Looking towards S16th Street

Looking towards the alley

Looking towards East

Looking towards south property

Context

Manhattan, Kansas is built along the grid- iron patters which dates back to the time when its early settlers planned this town. The demand for housing has existed in this city and many feel that the spilling out of housing units from the heart of the town to distant areas should be avoided.

Background

In July 2000 a study called *Housing Manhattan: Planning for the Future* was initiated to identify the housing potential for Manhattan by the year 2005 utilizing the 2000 Census data. The Plan identified that an additional 2902 housing units were required by the year 2000 out of which 918 would be owner occupied and 1,984 would be rental units. 20% of the new housing units were required to be the run-down houses that needed replacement while another 20% were to be affordable. This study suggested that the city should try to designate at least 70% of this housing demand or 2000 such new units. The demographics of the city also suggested that the age group from 19-34 and 65 years and older would demand a larger share of housing. Manhattan also needed to address the issues of housing retired and young families, which was estimated as 1,031 new units.

The population of Manhattan has been growing and the latest available data had predicted that by 2005, 17,601 households would reside in Manhattan out of which 10, 226 would be renters. Kansas Water Office (KWO) had projected that this population would increase to 51,466 persons by 2010 and 58, 105 persons by the year 2020. This would amount to an increase of 29.6% from the population in 2000 as shown in Table 2000 (http://www.ci.manhattan.ks.us/DocumentView.asp?DID=2598: 8/26/'08). Tables 2.3 and 2.4 and Figure 2.6 describe the increase in population as well as renters in the city (http://www.ci.manhattan.ks.us /index.asp?nid =491: 3/13/'08).

Table 2.3 Population Growth

(Source: http://www.ci.manhattan.ks.us/DocumentView.asp?DID=727: 8/28/'08)

Year	Population	Change (+)	Percentage (+)
1980	32,482	n/a	n/a
1990	37,712	5,230	16.10%
2000	44,831	7,119	18.80%
2005	46,468	1,637	3.60%
2010	51,466	4,998	10.70%
2020	58,105	6,639	12.80%

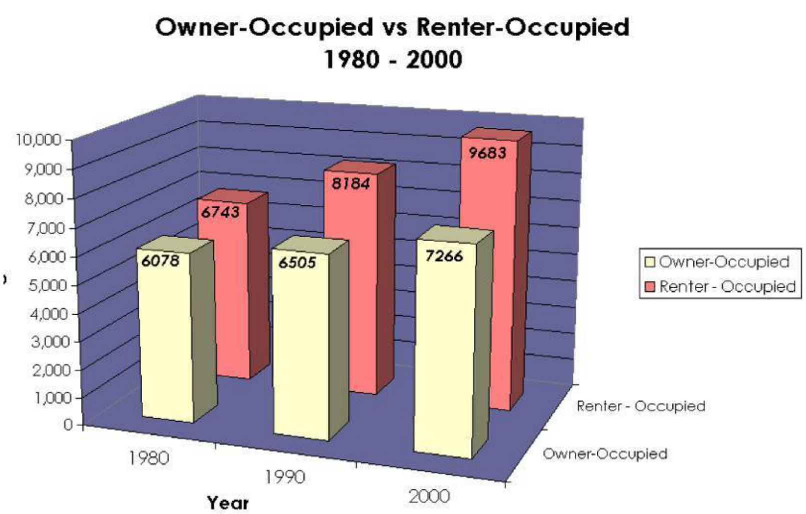
Table 2.4 Household Trends

(Source: http://www.ci.manhattan.ks.us/index.asp?nid=491: 3/13/'08)

	Total	Owner		Renter	
Year	Households	Number	Percentage	Number	Percentage
1980	12,823	6,075	47.40%	6,748	52.60%
1990	14,689	6,505	44.20%	8,184	55.80%
2000	16,949	7,266	42.80%	9,683	57.20%
2005	17,601	7,375	41.90%	10,226	58.10%

Figure 2.6 Owner-Occupied vs Renter-Occupied homes in 1999-2000

(Source: http://www.ci.manhattan.ks.us/DocumentView.asp?DID=2597: 3/11/'08)



The minimum housing vacancy rate for a community like Manhattan is estimated to be *5%.* However a vacancy rate of only 4.18% in 2000 was observed and the vacancy for year-round units was only 2.3%. These percentages certainly had to be boosted in order to meet the standards as well as to satisfy a home-seeker (http://www.ci.manhattan.ks.us /index.asp?nid=491: 3/13/'08).

The Manhattan Comprehensive Urban Area Plan: April 2003 was pulled together as a vision for the future growth and development of Manhattan, Kansas (http://www.ci.manhattan.ks.us/index.asp?NID=493: 3/13/'08). This plan intends to build a cohesive neighborhood with a variety of housing types. The plan promotes a neighborhood with mixed land uses and diverse housing options along with housing that is affordable. It also suggests that *new* or *infill* housing should be similar to the present neighborhood in *size, scale, design* and *use*. It advocates the establishment of new units within the *Urban Service Area Boundary* to provide the residents with necessary infrastructure and services for healthy community living.

The highlights of its *Housing and Neighborhood* goals are as follows (http://www.ci.manhattan.ks.us/index.asp?NID=493: 3/13/'08):

1. Help in stabilizing the older neighborhoods of Manhattan by *conserving, rehabilitating or redeveloping* the housing in these districts.
2. Provide a variety of new housing types which is also affordable to its residents, hence providing a mix of housing types for people with different income levels.
3. Develop new neighborhoods and housing types that afford *sustainability*, *connectivity* as well as a high *quality of life*. This suggests that neighborhoods should connect to nearby parks and open spaces, nearby neighborhoods and commercial areas.

The policies outlined in the section on *Housing and Neighborhood* of this report are outlined below:

- *'Mixture of Housing Types*
- *Encourage Construction of affordable housing*
- *Balance housing supply with employment/student base*
- *Stabilize older neighborhoods*
- *Promote infill and redevelopment*
- *Maintain quality of life in existing neighborhoods*

- *Facilitate neighborhood level planning efforts*
- *Promote coordinated neighborhood plan'*

(http://www.ci.manhattan.ks.us/index.asp?NID=493: 3/13/'08)

Thus it can be pointed out that a potential for developing housing in Manhattan exists, although this demand has its crests and troughs. Images of the existing and proposed land use plans for Manhattan, Figures 2.7 and 2.8 respectively, tell us that the city is spearheading towards large scale development and housing plays a major role in it.

Figure 2.7 Existing Land Use Map

(Source: http://www.ci.manhattan.ks.us/index.asp?NID=493: 3/11/'08)

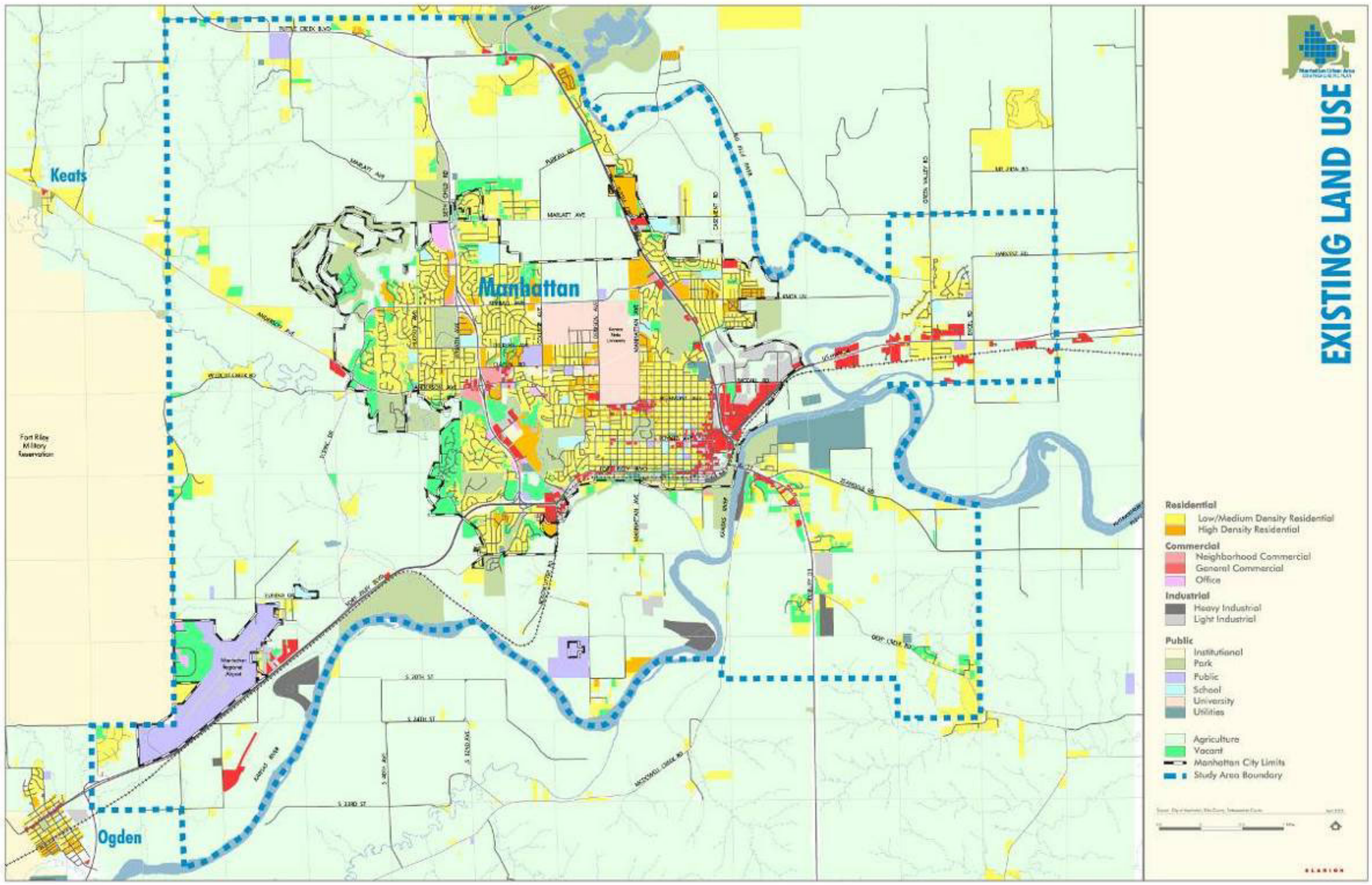
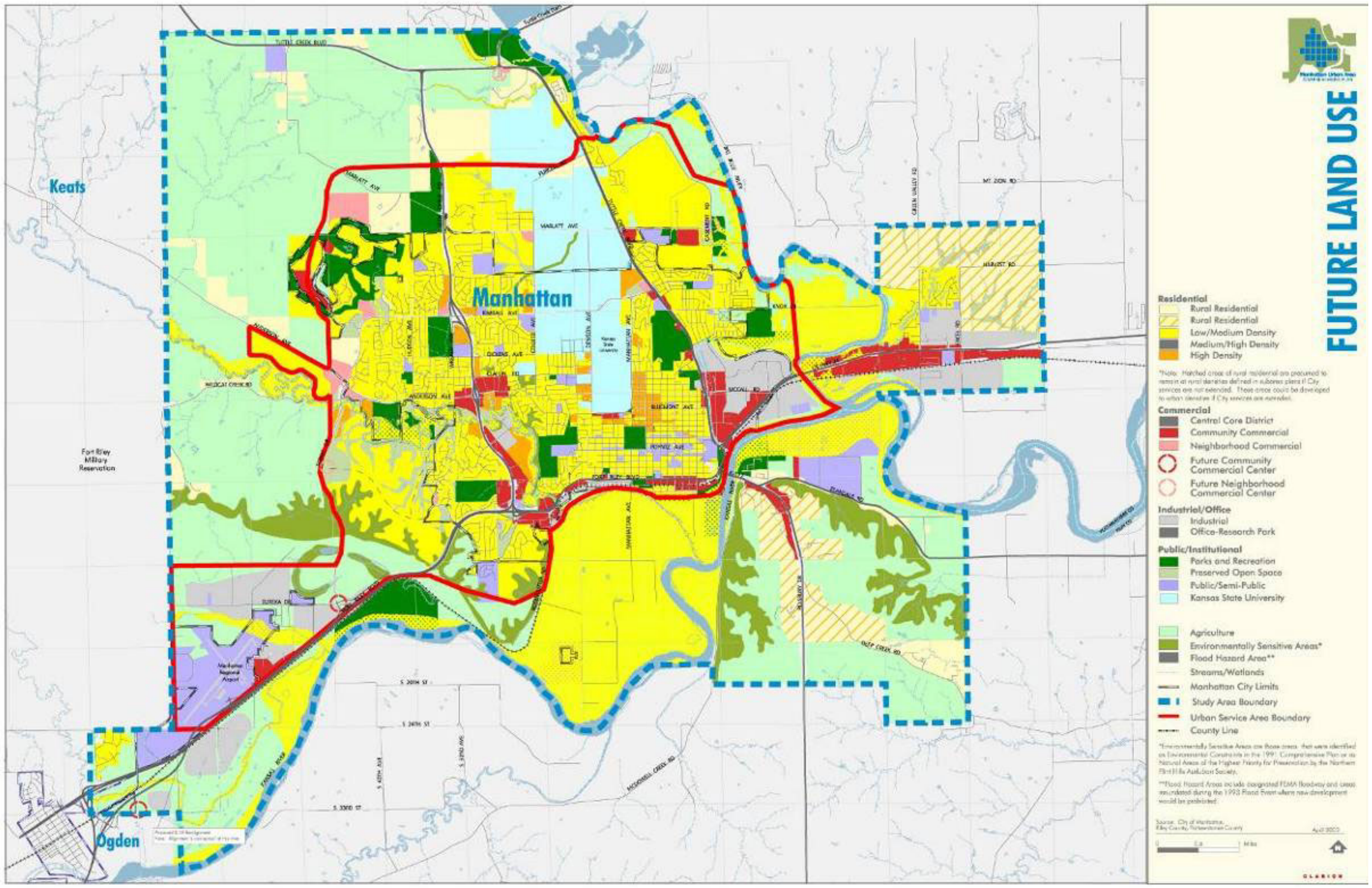


Figure 2.8 Future Land Use Map

(Source: http://www.ci.manhattan.ks.us/index.asp?NID=493: 3/11/'08)



Proposed Solution: Front and Back House Configuration

There has been dissatisfaction with the suburban sprawl and the cachet of the older residential neighborhood is trying to revive again. *'Americans continue to suburbanize, with metropolitan areas getting less and less dense. Is this sprawling of America too costly and unsustainable in economic, environmental, and social terms?'* (Douglas 2002, p.19) Instead of building elsewhere, the density of the present housing neighborhoods could be increased, replacing the decrepit houses with new and infilling the vacant lots. *'We must move back from cul-de-sac subdivisions to Elm Street neighborhoods, from drive through commercial strips to main street communities, quite simply from segregated sprawl to places more like traditional American towns.'* (Douglas 2002, p.24)

Since the university is one of the nerve centers of the town, housing around the campus can be developed following the lines of sustainable growth such as the theory of The New Urbanism. The New Urbanism theory proposes two kinds of planning strategies. One is the development of the main center until all the infill possibilities have been exhausted and the other is development of the region's edges. However, experts also agree that sustainable development of the edges of a city should be favored so that the vitality of the existing centers is not drained off. (Katz 1994)

Abiding by the theories of the former group of new urbanites, it is seen that the older neighborhoods of Manhattan have a huge potential to be developed into one of the kinds of towns much advocated by The New Urbanism movement. The older residential neighborhood is close to Kansas State University, schools and downtown, which also serves as a major employment zone for younger workers.

If these neighborhoods were made denser it would also lead to easy access to the shopping plazas, parks, churches, etc. for the residents and aging denizens. Instead of moving towards the periphery of the city, thereby triggering a new automobile dependent housing stock, costing a family over $6,000 per year to own and operate a car (Coates 2001, p.2), developing the core will make the life of the denizens, both young and old, pleasant. Moreover, it would also help knit a stronger residential fabric. If a household buys one less car, they save $500 towards the purchase and operation of housing (Douglas 2002, p.47).

The site chosen is close to Aggieville, one of the commercial centers of the city employing most of the youths (Coates 2001, p.2). Furthermore, elderly residents could also easily walk the short distance from the site to Aggieville as well as downtown. Being in one of the core districts of the city, the site is close to most of the elementary schools in the neighborhood and Manhattan Christian College as well as Kansas State University; students could easily walk to their schools and colleges. Manhattan City center is also close by the site. Hence, *walkability* to close by public areas, schools and commercial areas, which is one of the principles of new urbanism, is satisfied by the site.

Many of the successful towns following the paths of The New Urbanism, such as Kentlands in Gaithersburg, Maryland (built in 1988) and Windsor, Indian River County, Florida (built in 1989) have garage apartments and accessory units designed as an extra rental space for the home owners (Katz 1994). Hence, The New Urbanism encourages the construction of granny flats, rear cottages and backhouses to increase diversity in the neighborhood and provide affordable choices to both owners and renters.

It has been known that many home owners in Manhattan sublet their basement to students to help pay for mortgage. Hence housing types with such accessory spaces and backhouses will not only help in earning extra income but also increase the diversity and density of the neighborhood. These types of houses can be built to help home owners own affordable owner- occupied homes that have the advantage of being a source of extra income via their accessory apartments.

According to the research documented in the book *Affordable Housing* (2001), edited by Professor Gary J. Coates, if the city changes its present zoning to create a new overlay district to encourage the construction of *'not-so-big'*, energy efficient *' front houses'* as well as *'loftstyle cottages with backhouses'* then they could be *'used as home offices, apartments for aging parents or teenagers, or as rental properties, or as all of the above at various stages of the owner's life cycle.'* (Coates 2001, p.7)

The idea of creating mixed-income and diverse communities does not seem unreasonable today and these types of communities can be maintained. (Jones et. al, 1995, p.10) The Zero Energy Infill House is proposed keeping in mind the present housing demand in the city of Manhattan, goals of the Manhattan Comprehensive Urban Area Plan, the changing lifestyles of the people as well as the principles of The New Urbanism.

The design matrix proposes a range of solutions and is comprised of an owner occupied adaptable front house with a basement planned as an apartment that also can be leased out. It also has back house rental units for students, young couples, retired personnel and residents needing assisted living. Manhattan being one of the ten best places in the USA to retire young, this proposal provides a helpful source of income for the retired individual as well as affordable rental housing. A variety of such lifestyle and life cycle scenarios are considered.

The possibility of the 'live and work' scenario has also been explored in the matrices. This increases the density and also promotes income generation for the owner through the rental units assisting towards an affordable housing solution. Such houses, if used to replace the deteriorating houses in the neighborhood, could help increase the density of the neighborhood, consequently achieving *increased density* - one of the principles of The New Urbanism. This combination of housing units proposed can be utilized as infill housing in the older residential neighborhood and can also replace the run-down structures. It is also observed that the change in household patterns and demographics are harbingers of a demand for a varied lifestyle which has also been dealt with in the designs of the units.

The older neighborhoods of Manhattan represent an '*important and irreplaceable architectural and cultural resource for the entire city as well as an attractive location for housing development.'* (Coates 2001, p.2) *'Relevant urban traditions and contemporary demands must be fused to achieve a new urbanism.'*(Kelbaugh 2002, p.xii) The image of the houses in the residential locality has been conserved avoiding any alien features in the elevations so that it blends into the neighborhoods. Although it lends to multifamily housing (since a range of household types can occupy it), it has been built with the vision of a neighborhood home in contrast to the box-like apartment buildings that distort the image of a residential area.

The Zero energy house further investigates the possibility of curtailing the utility costs of the house to render the house an energy-efficient solution to the skyrocketing energy prices and global warming. The question of affordable housing has always been in the forefront; although this study does not directly answer the issues of affordability, it does extend its efforts towards answering the issues of economic viability. '*Ideally all housing should be affordable to those living in it.'* (Jones et al. 1995, p.8)

CHAPTER 3 - Design

This Chapter presents the most important findings from this study in a detailed fashion. Typical design procedures were employed with conceptual sketches being developed into plans, elevations and sections which were in turn constantly scrutinized and reconfigured. The design is the end product of a thorough study of the spatial needs of the present day American family along the guidelines laid out in the Manhattan Housing Plan, Manhattan Comprehensive Urban Area Plan, New Urbanism and Bioregional design strategies. Zoning and building codes, accessibility standards, graphic and visual codes also provided a helpful template in arriving upon a plausible design solution. A matrix of design solutions was compiled that could be readily accommodated at the chosen site. A thorough discussion of this matrix is followed by a presentation of all architectural drawings in the form of plans, elevations, sections and perspective views.

Front and Back House Design

'New housing should inspire hope for a better living.' (Jones et al. 1995, p. 59)

The study by Professor Coates and his students documented in *Affordable Housing* (2001), Harini Sarangapani's thesis on "Zero Energy Garage Apartment" and literature review coupled with a thorough study of local needs and housing requirements of Manhattan all indicated that the *Front House/ Back House* design concept could be further explored. It was clear that a design matrix could be created to present a gamut of solutions that could be incorporated into the existing residential fabric of Manhattan.

The design matrix would serve as a *pick-and-choose* set of housing options for developers or home owners, similar to the variety available in many home-design magazines. Any one of these designs could be used as an infill option in many multi-family residential districts in the city and could also be used to replace dilapidated properties in similar zones. Since most of the lots in the city are elongated in the north-south axis, this design could thus be repeated in other similar locations; hence it could well be utilized as a prototype.

Some of the advantages of the front house/ backhouse typology are listed below:

- It provides enough space that can be used in many ways and by multiple people.
- Many cultural groups that include in-laws and parents in a household can be accommodated in the back houses leading to an affordable want of living.
- Growing teens can occupy such quarters so that they have their own space and feel free yet close to home.
- Divorces are getting more frequent today; such back houses can provide shelter to divorced son/daughter who returns to stay with his/her parents when they cannot afford to live elsewhere.
- The back house rentals are useful even for grown-up children who do not have a stable/sufficient income and return to stay with their parents. When the parents cannot afford to buy their children a house, the least they can do is give them a home in their backyards which is a separate household yet close to the parents' house. The front house itself can be designed to accommodate children who

return due to failure of income or wish to stay and work in the same city as their parents and cannot afford to live elsewhere.

- The back houses could be rented out to starter families or students at reasonable rents making it affordable.
- Rented backhouses help the owner to generate a steady income, thus helping him or her to pay for mortgages, maintenance, taxes etc.
- The owner can move into such a back house when he is alone and old and rent out the front house. This can help him pay for his medicine and give him or her some income. Many older home owners who do not wish to leave their homes after getting old can thus still stay in their premises and neighborhood and afford it too.
- The basement can also be configured into an apartment with ample daylighting and ventilation and could be subleased to students generating income for the owner.
- Such front house/ back house combinations shall lead to a close knit social fabric which is not too close like many apartment buildings, yet there is a sense of community living. '*Well-designed housing can and should provide the basis for a true community-building process. That is what we mean by 'design excellence in affordable family housing.''* (Jones 1995, p. 10)
- Diversity as well as increased density is achieved in the neighborhoods helping people live in the premises of the city with easy access to the various infrastructural services of the city.

Many of the above uses of the backhouse are similar to Dolores Hayden's research which has been described in the introduction of this study. The said housing option serves not only the owners but can be used to satisfy multiple occupants in its lifetime. The house can thus be exploited to its maximum capacity.

Design Goals

The general goals for the front and back house design presented in this thesis have been outlined below. The author hopes that the reader finds that within the scope of the work presented herein, most if not all, of the design goals have been addressed and resolved.

- **Design separate structures on the site**: In order to maintain the identities of the structures built on the site, the front and back house were conceptualized as separate structures.
- **Maintain privacy**: The front and the back houses were designed to house a 'mini-community' in itself where multiple families could live. Hence, while it was intended to provide a certain degree of interaction within the residents, it was also necessary to maintain their privacy. The front house, therefore, has its main entrance from the sidewalk abutting Poyntz while the backhouse is accessible from the sidewalk next to S 16th Street. This concept is similar to "Case Study House # 1" (p. 42) in the Blueprints for Modern Living (1989) as shown in Figure 1.1. Open spaces for both the structures have been divided by a dwarf wall and tall shrubs.
- **Use bioclimatic design strategy**: Bioclimatic design strategy, discussed later in this Chapter, played a key role in interior planning as well as site planning of the structures.
- **Provide sufficient open spaces**: Since two structures were to be designed on the same lot, care was taken to provide adequate open spaces for each household in the form of back yards and patios. In comparison to apartment buildings, with fewer opportunities of outdoor spaces, these designs have been provided with compact outdoor spaces for the residents in both the front and back house. The City Park, which is at a close proximity to the site, acts as an outdoor amenity for the residents. Sunspaces have been added in some of the housing types which could be potential gardens for the houses. In comparison to houses with a great deal of yard and lawns to take care of, this housing type presents more compact, manageable and usable outdoor areas.

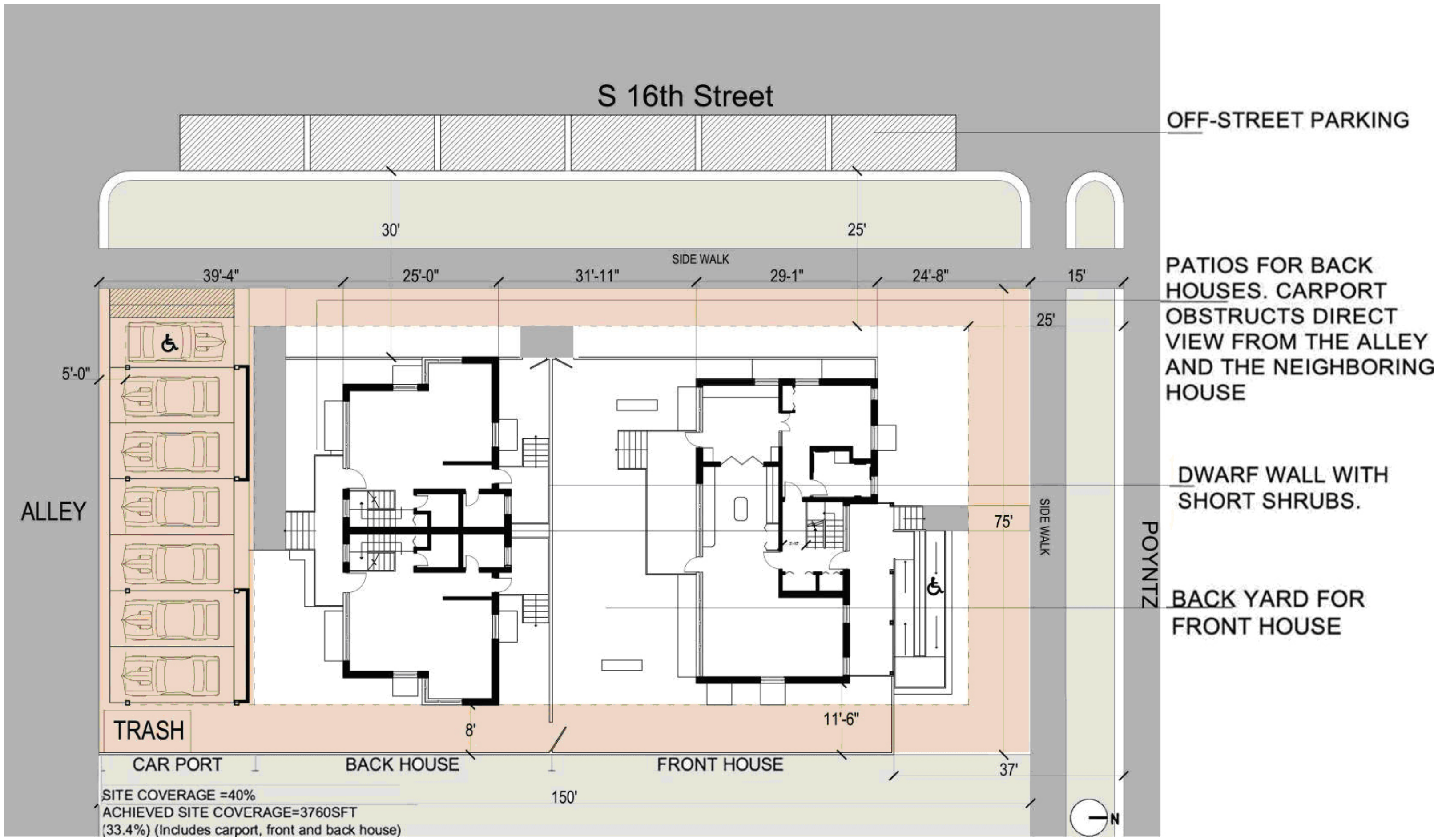
- **Treat the four facades equally in terms of elevation**: The front house faces Poyntz, the side elevations of both the buildings are visible from S 16th Street while the carport and back houses can be seen from the alley. The elevations are all similar to those of the other residences in the neighborhood so that it blends well into the surrounding.
- **Provide as many bedrooms as possible in the front and back houses**: This was necessary in order to facilitate income generation in case the houses were to be rented. Double storey rooms have, therefore, been avoided, instead dedicating the volume to another room.
- **Provide for accessibility**: Accessibility and 'special needs' issues have been addressed in the designs
- **Provide a tornado shelter for all residents.**
- **Provide daylighting and natural ventilation for basements**: It is often noted that basements are dark and dingy places in which to live. Appropriately lit and ventilated basement living spaces have been provided for in the designs presented herein.

Site Utilization

City zoning codes helped in defining the built-up areas and the building heights. The set-backs and zoning codes have been included in the appendix. Figure 3.1 represents site utilization. Setbacks used in the project are in accordance with the Manhattan Zoning Regulation amended and reestablished on October 16th 2006. The front yard setback was established by measuring the widths of the front yards of the existing buildings in the neighborhood. The side yard set-back (abutting S16th Street) was also aligned to the adjoining house. The front porch plinth heights of the existing houses in the block were measured and a similar height was used in this design. The total site coverage achieved was 33%.

A shaded carport was provided next to the alley. Decks and open spaces have been provided in the front and back house design. A dwarf wall with short shrubs delineates the front and back house while also maintaining a sense of privacy.

Figure 3.1 Site set-back



Space Requirements

Since the project did not have any specific client, the decision about the spaces to be provided in the design was primarily obtained by going through numerous home magazines and design books such as *The Adaptable House* by Avi Friedman (2002). Spaces that were identified as an important and essential part of the household were provided in the design. The design matrix includes a variety of options with various combinations of spaces. In some cases, spaces have been utilized for alternative purposes, thus leading to an entirely different design type. The houses are designed as compact spaces to avoid wastage of spaces in circulation, and so on. It is often observed that rental units have poor storage facilities; therefore, care was taken to provide a reasonable amount of storage in the front house and the back house units. The steep pitched roof facilitated implementation of this requirement.

Lists of the spaces available in the front and back house have been tabulated in Table 3.1. The parameters used in designing the spaces have been briefly mentioned in this Table. With the set of requirements thus outlined, the design task was set and consequently undertaken.

Table 3.1 Spaces Provided and Design Parameters

Front House	Design Parameters	Back House	Design Parameters
Porch	Means of connecting the outside to the home.	Porch	Warm, southfacing outdoor area connecting the home to the streets.
Entrance Foyer	Shared space for multiple residents.	Kitchen	Single space flowing into each other. Ample south windows for a warm, light filled space.
Kitchen	Single space flowing into each other. South windows for a warm, light filled space.	Dining Room	
Dining Room		Living Room	
Living Room		Bedrooms	Decent size which is well lit and ventilated.
Home-office	Accessible and close to entrance.	Bathrooms	Decent size which is well ventilated.
Bedrooms	South facing with a decent size and storage facilities.	Utility Space	Adequate area with easy access from outside.
Bathrooms	Decent size which is well ventilated.	Storage Facility	Ample storage facility.
Utility Space	Adequate area with easy access.	Outdoor Lounges	South side open spaces for outdoor living.
Storage Facility	Ample storage facility.	Sun-Spaces	For passive solar heating and as an additional living space.
Outdoor Lounges	South side open spaces for outdoor living.	Parking	Coverd parking to protect against the weather.
Sun-Spaces	For passive solar heating and as an additional living space.		
Parking	Coverd parking to protect against the weather.		

Bioregional Design Strategies Employed

Every region has its climatic characteristics and a unique list of architectural responses. Although bioregional design strategies have existed for centuries, they are seldom used by designers today. Sophisticated energy intensive mechanical systems may possibly make a glass box comfortable for use even in the middle of a desert, but at a cost of endangering the earth's stability because of its excessive dependence on fossil fuels.

Manhattan, Kansas, has a generally temperate climate and its unique set of bioregional design rules help in decreasing the energy requirements of housing. During hot summer days, bioregional architecture helps in keeping a space cooler while during the cold and chilly winter days it assists in providing warmer spaces. The biggest challenge in this design exercise was to provide bioregionally appropriate design responses for the entire matrix of the dwelling design. This Chapter broadly describes the bioclimatic strategies used in all the designs. Specialization and changes in the design, to achieve higher energy performance, have been presented in the Chapter on energy analysis which also presents a thorough bioclimatic analysis and calculations for one of the designs from the design matrix.

The fundamental climatic design goals for this continental temperate region are:

- **Winter:** Keep the heat in and cold outside. Design to allow the sunshine into the house and keep out the cold winter winds.
- **Summer:** Keep the heat outside. Shade the house from the hot sun. (Coates, G. 2007)
- **Fall/Spring:** Provide opportunities for cooling breezes to flow through the house.

Design decisions for achieving the above goals:

Plans and elevations for enhanced solar access and ventilation: Both the front and back houses are oriented in the elongated east-west axis leaving a reasonable cavity in between the two buildings so that there is enough amount of solar access to the front house in winter as illustrated in Figure 3.1 which represents the site plan for all the houses in the matrix. The living, dining, kitchen and most of the bed rooms were placed towards the south for better access to the sun in winter. All the rooms in the basement apartments were provided with light wells not only as a means of fire escape but also to provide access to the south sun, proper daylight and ventilation. By these means the claustrophobia of living underground is eased to some extent with well lit, warm spaces. Spaces such as baths, laundry, stairs and storage were provided its the north in each design in view of the fact that it would be the colder edge, especially in bitter winter weather. Figures 3.2 – 3.5 explain these concepts.

Figures 3.6 and 3.7 give an idea of the winter sun at its highest point and the relationship between the different sections of the houses. The houses were spaced so that the south façade of the front house had enough solar access. In order to better harness the warmth of the sun in winter, some designs have sun rooms with ventilators on the wall to permit circulation of warm air into the living units. The ventilators at the top also facilitate better cooling during the hot summer days together with the use of drapes, blinds or canvas covers. All the house types have outdoor decks and patios located toward the south in order to let residents enjoy comfortable outdoor stays during warm winter and cool days in spring and fall.

Large windows on the south façade help in inviting more sun into the spaces. Windows were kept at a minimum in the east wall; however, windows could not be avoided on the north and the west facades since these facades face the streets and need to present a sense of openness to the public realm. As a result, a reasonable number of windows have been provided in these facades. Casement windows were used in order to reduce infiltration of hot or cold air. Almost all rooms have been designed to allow for cross ventilation. All the windows are of the "double glazed Low-energy" type with shading devices in the south façade for protection from the summer sun. The roof is pitched at an angle of forty degrees. This pitch was chosen in view of the fact that the latitude of Manhattan is thirty nine degrees. If the occupants were to ever decide to use solar panels later, the pitch would be ideally suited for the PV system.

Figure 3.2 Bioclimatic Site Plan

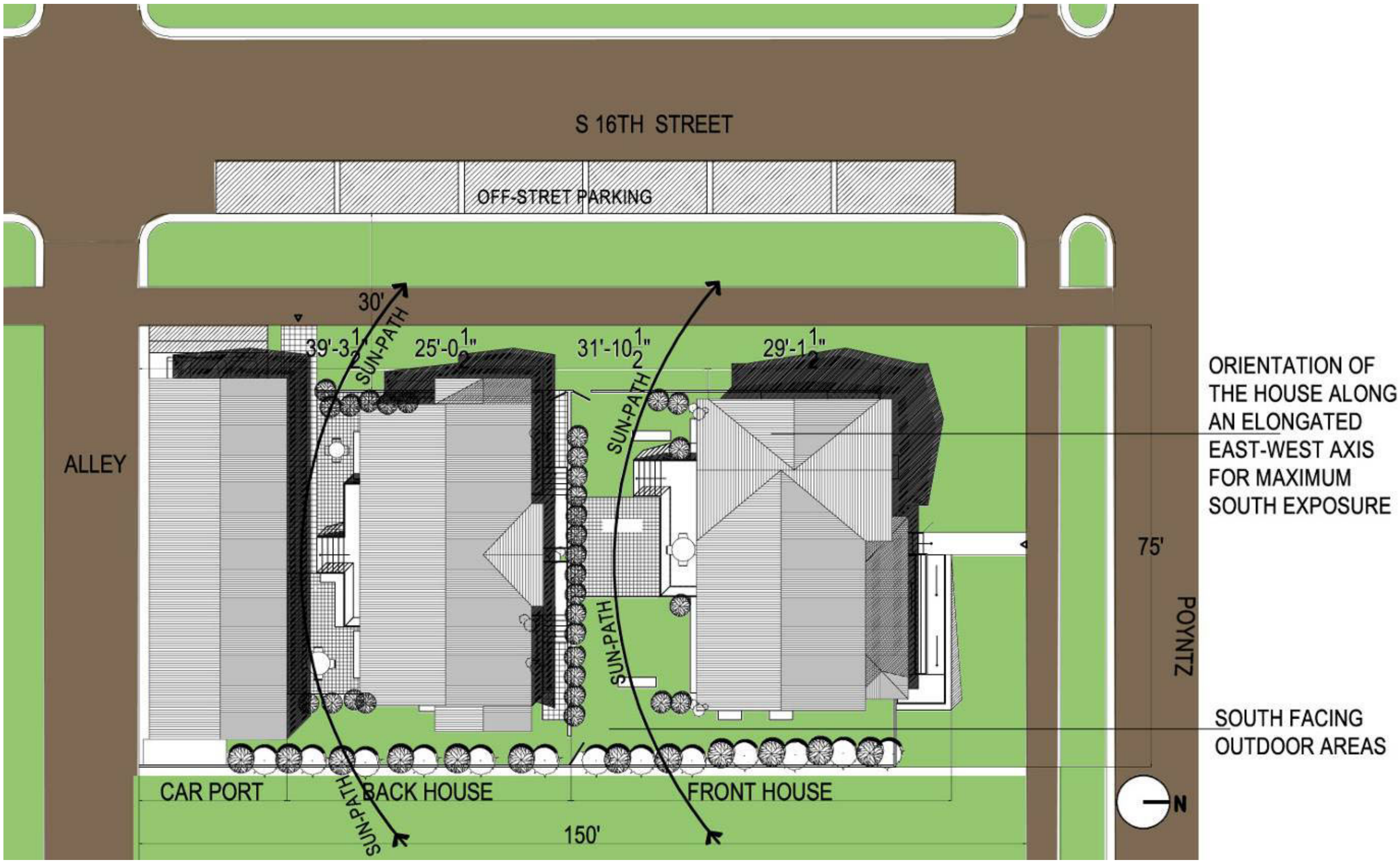


Figure 3.3 First Floor Plan

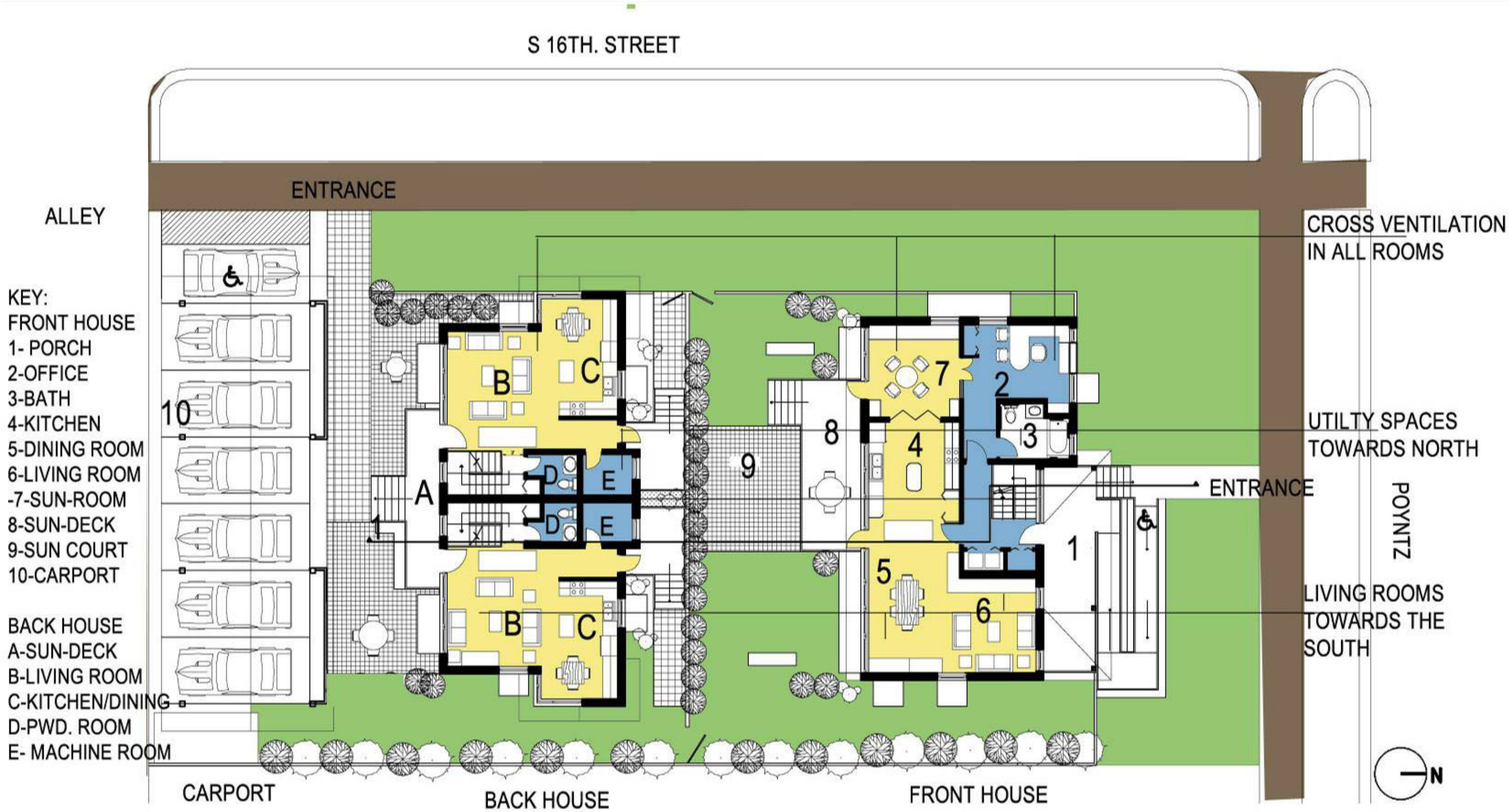


Figure 3.4 Second Floor Plan

Figure 3.5 Basement Floor Plan

Figure 3.6 First Floor Plan with Sun-room

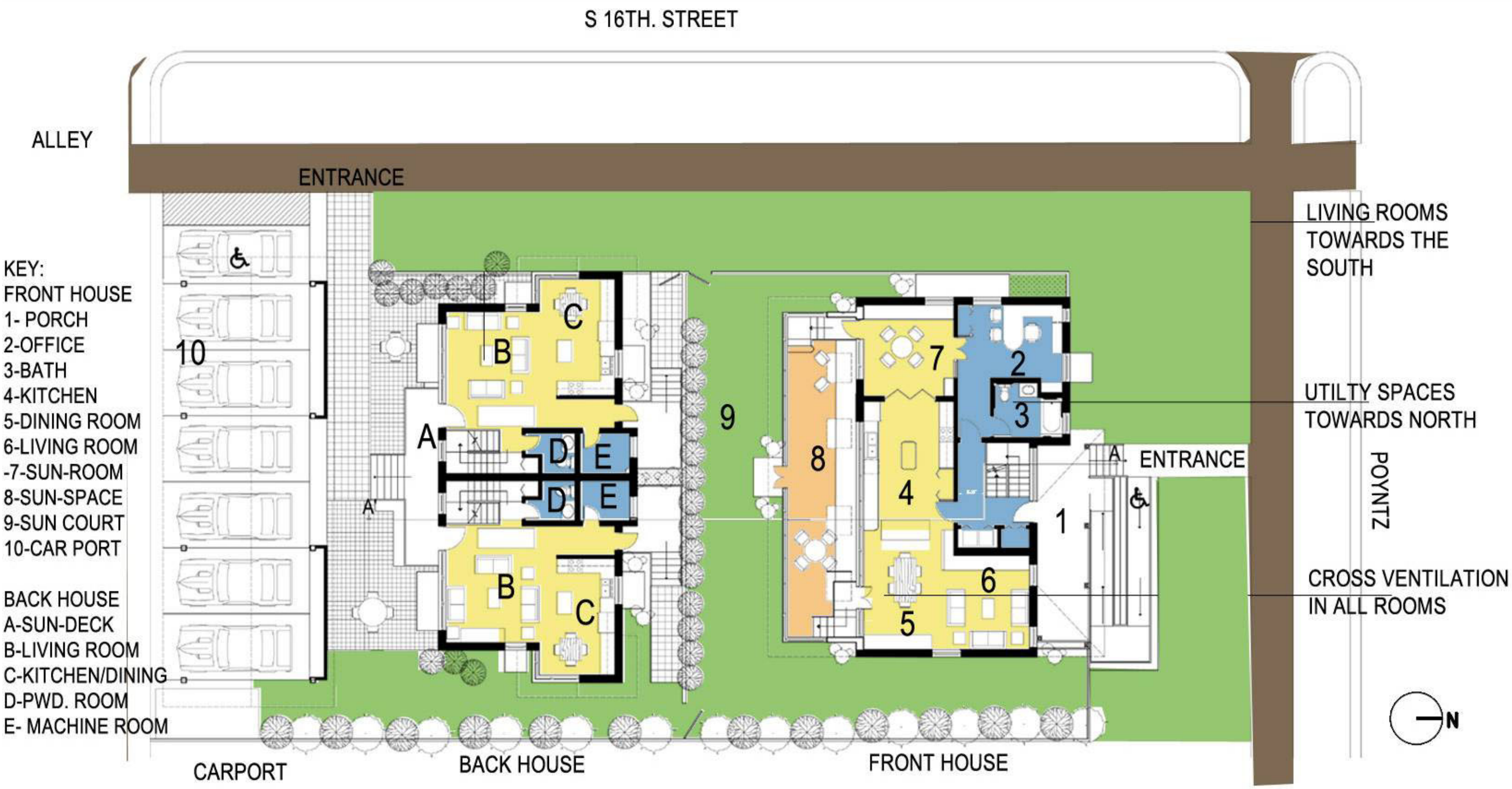


Figure 3.7 Longitudinal Section 'AA' of a typical house

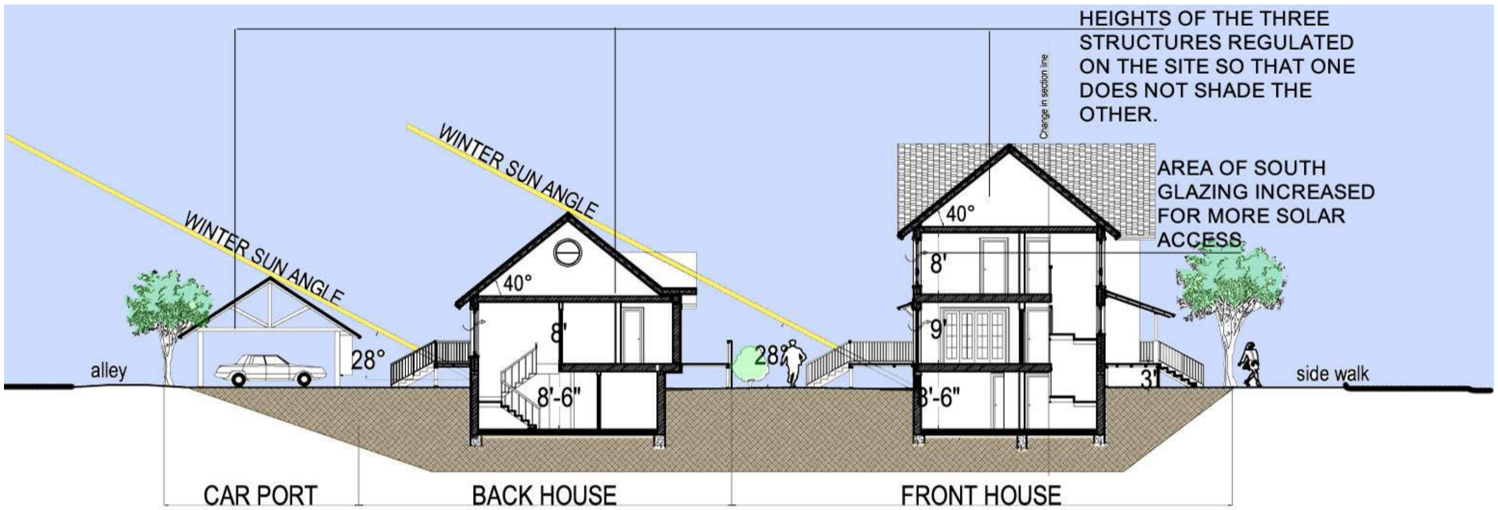
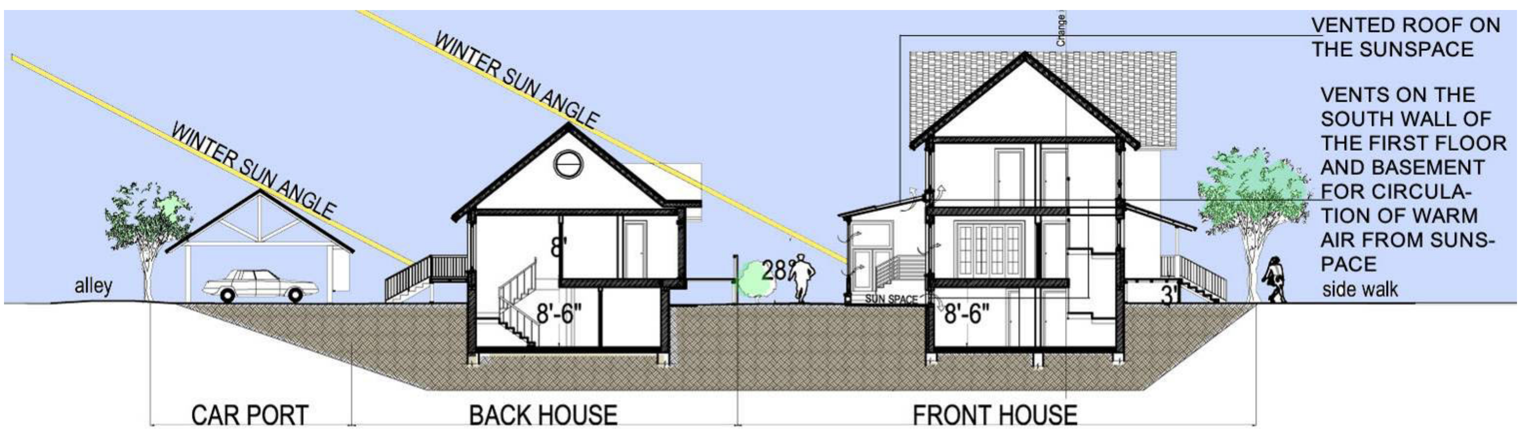


Figure 3.8 Longitudinal Section 'AA' of a house with Sunspace



Insulation: Incorporating good insulation into the design was critical to achieving the thermal performance goals, for it would not only help keep the heat in during winter but also keep the heat out during summer. The use of Structural Insulated Panels (SIP) for construction was visited, however, due to lack of local 'know-how' this material was not chosen for this thesis. This material would also be expensive if not used skillfully and without much wastage. Instead, 2X6 wood construction with blown polystyrene insulation was used in the walls to achieve an R-value of 23.1. This is fairly close to the R- value of 6.5" SIP wall panels (23.8). Since a considerable amount of heat gain/loss also occurs from the roofs, ample amount of sprayed insulation was provided on the attic floor. This contributed to a total of R value of 49 using 2X6 frame construction for the attic floor with 10" deep blown polystyrene insulation and radiant barrier on the roofs.

Earth integration was utilized for the basement apartments thereby reducing the overall heating and cooling load for the building. The basement has 8" nominal C.M.U. walls with 4 inches of insulation while the floor is made up of a 4" concrete base, thus boosting the overall R- value of the walls as will be illustrated in the calculations that follow.

The Design Matrix

The design matrix presented in this section is the outcome of numerous permutations and design revisions. The original design options had to be revised for code compliance and for handicapped access. This matrix presents thirteen architectural design options for housing in a lot that is 50' X 150' in the residential neighborhood of Manhattan with and R-3 multifamily zoning allowance. The design divides the lot into four parts, viz. the front house, the back house, carport and open spaces for outdoor living. The design was thus conceptualized as a home that could be used by a person during various stages of his/her life while generating rental income or providing shelter to a close kin needing support. In the matrix the option of "aging in place" is also explored.

The matrix as shown in Figure 3.9 is divided horizontally into three major types: Type 1, Type 2 and Type 3. Each type of them has sub-types achieved by variations in the architectural characteristics and heights of the designs. While two bedroom homes are common, large families are often inadequately served by housing market facilities since it is uncommon to find homes with three to four bedrooms (Jones et al.1995, p. 16). An attempt has been made in this study to maximize the options for achieving as many bedrooms as possible instead of providing double height spaces.

Parking facilities have been provided in the rear with a carport with ample storage area. Seven cars can be parked in the carport and six cars can be parked off the street (S 16th Street). The elevations are mostly repetitive with minor changes in some schemes. The elevations have been designed to fit in with the surrounding residential neighborhood.

The total area of the lot is 11250 sf (150'X75') or 0.258 acre. Hence assuming the front house as dwelling unit with two dwelling units in the back house, in all the design types, the housing density achieved in this design is 3 dwelling units/0.258 acre or 12 dwelling units/acre. However in the case of Type 1e where only one back house dwelling unit is designed this density decreases to 2 dwelling units/ .258 acre or 8 dwelling units/ acre. Calculation of the density on the basis of the number of households will be different which have been defined in the sections describing the housing types in detail.

Different types of families have been accommodated in a single lot hence increasing the density and diversity in the residential neighborhood. It is possible that, with multiple occupants living on a single lot, maintaining privacy might be an issue. However, landscape elements have been utilized to alleviate the possibility of this to some extent. Furthermore, outdoor areas have been segmented so that each household has their share of outdoor space.

The design options 1a, 1e, 2a and 3b have been documented in this Chapter and the rest of the subtypes are shown in Appendix B of this thesis. A more detailed discussion of the three types of houses is provided below.

Type 1 Houses

The front house is designed for use by larger families. A home office is provided in the house to accommodate a "live and work" scenario. Since the home office was meant to be a public space, associated spaces such as entrance ramps, baths and the office itself are also made accessible. The entrance ramp has a slope of 1:12; all the doors were designed to be 3' wide with passages 3'4" wide. The bath as well as the office has a 5' turning radius to allow for wheelchair access. The kitchen is also accessible since the work island could be moved if required, leaving a larger circulation space. The closets in the entrance are wide enough for storage of washer and drier if required. After retirement, the office space could be converted to a bedroom and used by the owner, especially if walking to the upper floors becomes difficult or impossible. The upper floor could then be used by a close kin or possibly even rented out for additional income or for use by someone whose 'job' is to provide homecare.

The accessible first floor could also be occupied by an elderly parent or in-law. Another advantage of the office space is that if the door leading from the kitchen to the sun-room were to be locked, it becomes an independent living space in itself. Hence, such a room could be rented out or even given to a teenage child or a child attending Kansas State University who needs privacy, while staying in his or her parents' home.

This type has four bedrooms in the front house with basement rental units and back yard rental units for smaller families or students.

The household density achieved in this case is 4 households/ 0.258 acre assuming a front house with a rental basement and two back house rental units. Hence the density would be 16 households/ acre.

In summary Type 1 houses exhibit flexibility. They may be occupied by larger families or families requiring home offices. They may serve as a multi-generational house when the accessible office is used by an aging parent or an elderly in-law as a bedroom. Aging-in-place is accomplished in this type of house, since the owners could restrict themselves to the accessible first floor and rent out the upper floor or allow a close kin to occupy it.

Type 1e is presented as an additional variation wherein the back house is a single storey, adaptable house for a single family. This could be an option if the owner decides to move into this apartment when he/she gets old, which would allow the entire front house to be rented. Given the close proximity of Fort Riley and the possibility of return of the soldiers with disabilities, the rear apartment is designed as an adaptable unit for renters with disabilities. Further details regarding Type 1a and Type 1e houses are documented later in this Chapter. The rest of the types are included in the appendix.

Since only one backhouse is designed in Type 1e, hence the household density in this case is 3 households/0.258 acre or 12 households/ acre.

Type 2 Houses

In a Type 2 house, the front house is designed for three separate households. The design is similar to a Type 1 house; however, in this case, the demarcation of spaces for each household is more distinct. The office space in Type 1 houses is now designed to function as a bedroom with a handicap accessible bath. The option for aging-in-place is presented more explicitly in this case. The retired owners can occupy the first floor, hence avoiding the necessity to climb stairs. All the rooms in the first floor have a 5’ turning radius for ease of movement of residents requiring wheel chair accessibility. Many elders do not enjoy moving into retirement homes and this could be a viable option for them.

The second floor is demarcated as a separate apartment by an entrance door. This apartment may be occupied by the owner's children or else rented. Thus, this Type 2 house has a basement rental unit, an owner occupied adaptable first floor unit and a three bedroom second floor rental unit for students or families. The entrance foyer serves as a common space for all the households. The back yard has two duplex rental units as seen in other house types.

There are five households in this scenario, with three households in the front house and two households in the back house. Hence, the total density in this case is 5 households/ 0.258 acre or 19 households/ acre.

Type 3 Houses

Type 3 houses can accommodate three types of occupants. This option also is an example of a multi-generational house. The versatile office space, opening from the entrance foyer in Type 1 house, gives this house type yet another dimension. This space, with the adjoining sun-room, is now intended to be a studio apartment. This could very well be rented to a single individual like a student who needs more space. This type of apartment can also be used by an elderly in-law, which is a common trend in households today owing to the growing expenses of old age homes. Adaptable baths are designed to serve this end. The sun-room doubles up as a kitchen and dining space for this studio apartment.

The rest of the front house could be occupied by one family, renting out the basement apartment. Hence, this option gives a picture of a multi-generation house or a house with multiple occupants. The back houses are designated as rental units in this case as well. The total household density in this case is also 5 households/ 0.258 acre or 19 households/ acre, assuming three households in the front house and two in the back houses.

In all of the three housing options, the back house has been used as rental units generating additional income for families while the front house has been explored for its flexibility. The number of home renters has steadily increased in Manhattan as shown by data presented in Chapter 2. The back house units target this population. In these three types the same building envelope is modified in various ways to achieve flexibility. The foyer and stairway at the entrance, which is carefully curtained from the living areas, supports the use of the house by multiple users. With tornados being a major concern in this region, options for tornado shelters are also provided.

Figures 3.10- Figure 3.13 show the views of the front and back house. A typical design consisting of a back house with basement and two rental units have been utilized for the generation of this three dimensional graphic. All the views give a sense of the form and massing of the structures. Figure 3.13 shows the outdoor areas in each house hence each occupant has access to outdoor spaces though the sundecks, front and back yards.

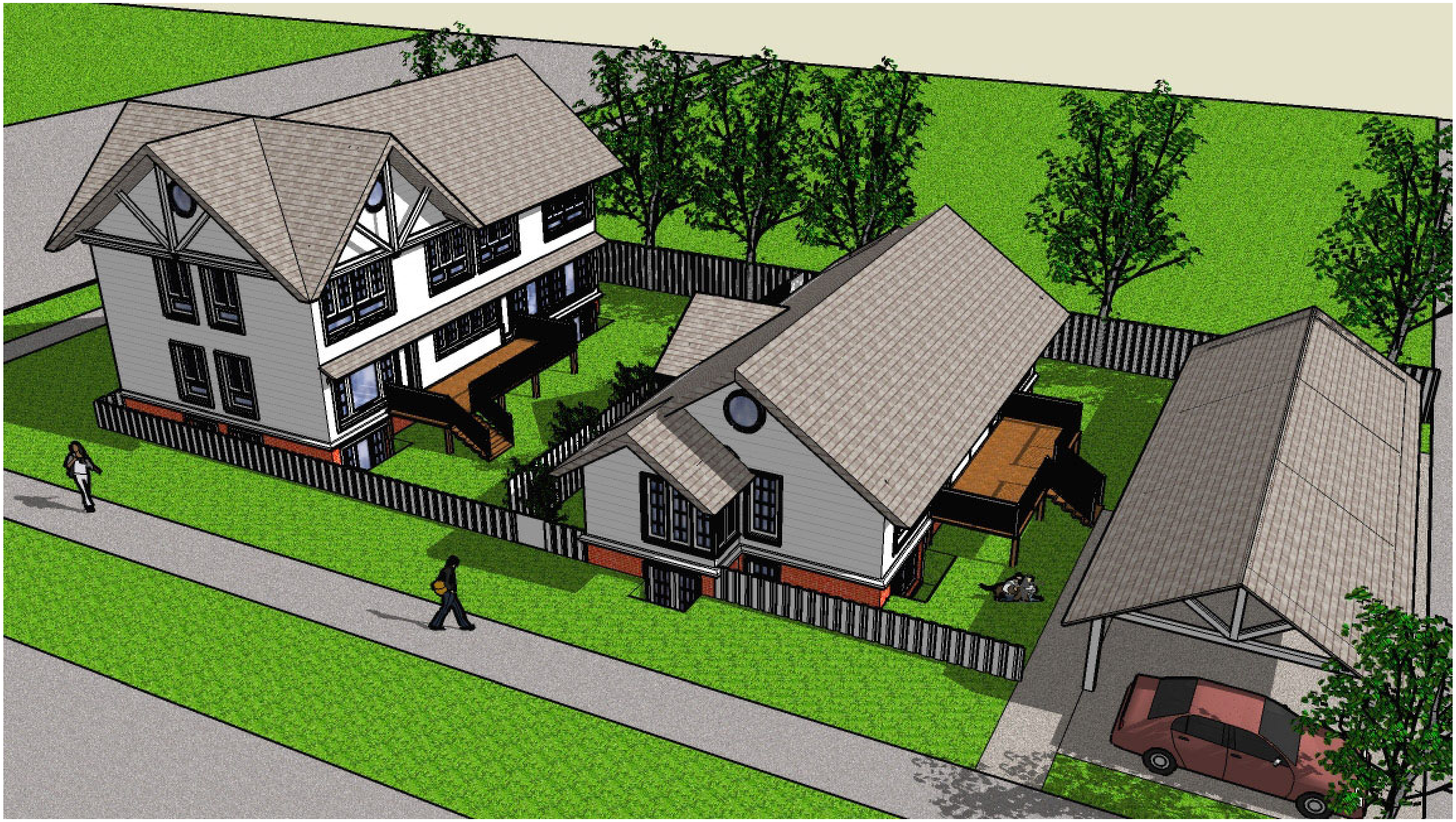
Figure 3.9 Design Matrix

Figure 3.10 View of Front House from Poyntz Avenue

Figure 3.11 View of Front and Back House from Poyntz Avenue

Figure 3.12 View of Front and Back House from S 16 Street

Figure 3.13 Bird's eye view of Front and Back House showing the outdoor spaces



Type 1 Houses: Front house with a home office occupied by owner, back house and basement as rental units

Type 1 houses branch out into five different types each resulting from the integration of subtle architectural variation. Due to the presence of a home office the spaces committed to public use had to be made accessible. Thus the baths, parking and accesses are designed to satisfy the accessibility requirements.

Type 1a House

This proposal provides a sun deck towards the south in the front and back house units. The back house has bedrooms in the basement with living/dining areas on the first floor. The basement apartment in the front house has an area of 1,100 sf. while the front house covers 2,600 sf. Each apartment in the back house is 1,230 sf. Due to the back house being pushed in the ground, the front house receives more solar access.

Since both the front and back house units have basements, they serve as protective spaces during tornadoes. The basement windows have light wells that also double up as fire escapes while allowing for the admittance of sunlight and natural ventilation. The light wells are compliant with the fire codes. All rooms are provided with sufficient openings to allow for cross ventilation. This design is used for energy analysis and economic analysis documented in Chapter 4 and Chapter 5 respectively.

Figure 3.14 1a Location Plan

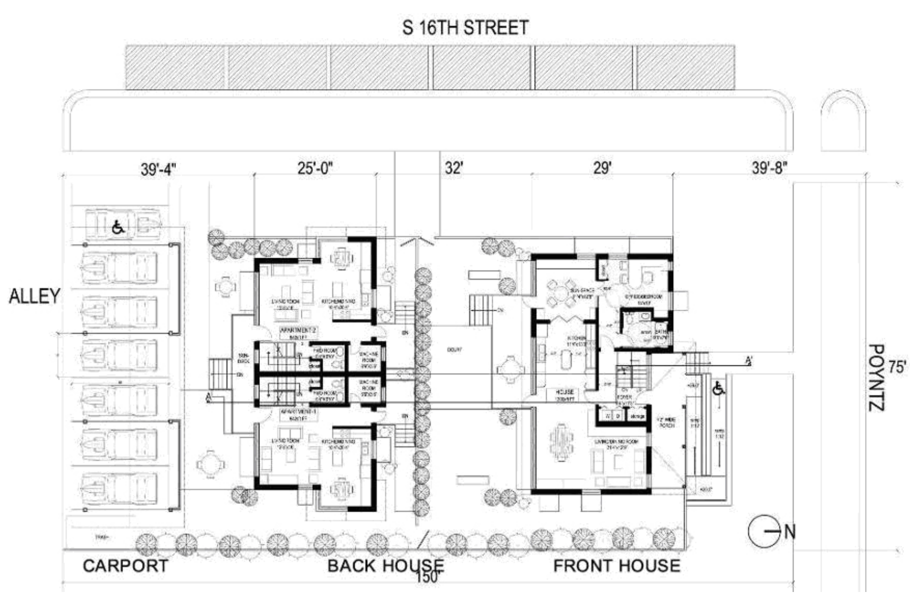


Figure 3.15 1a First Floor Plan

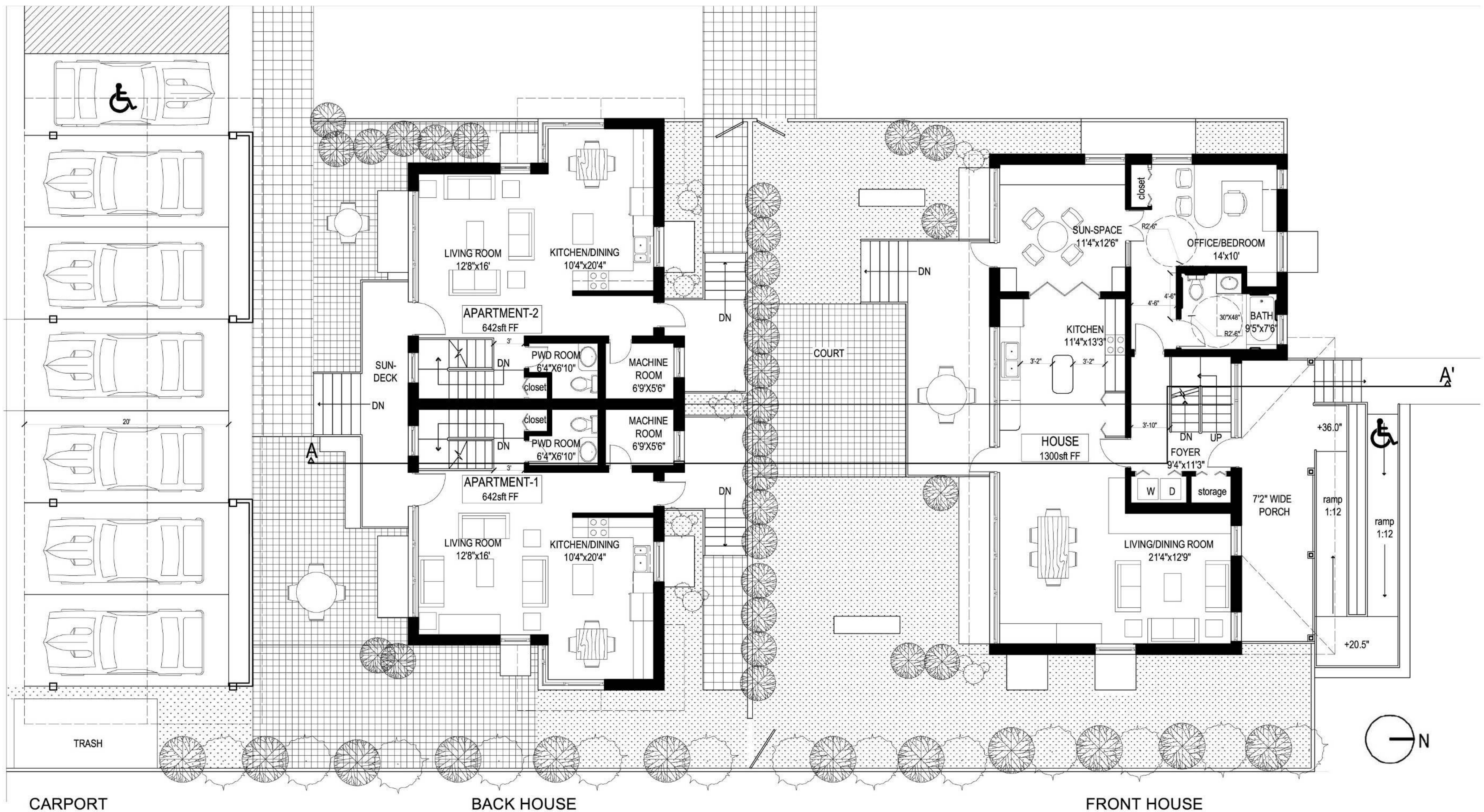


Figure 3.16 1a Second Floor Plan

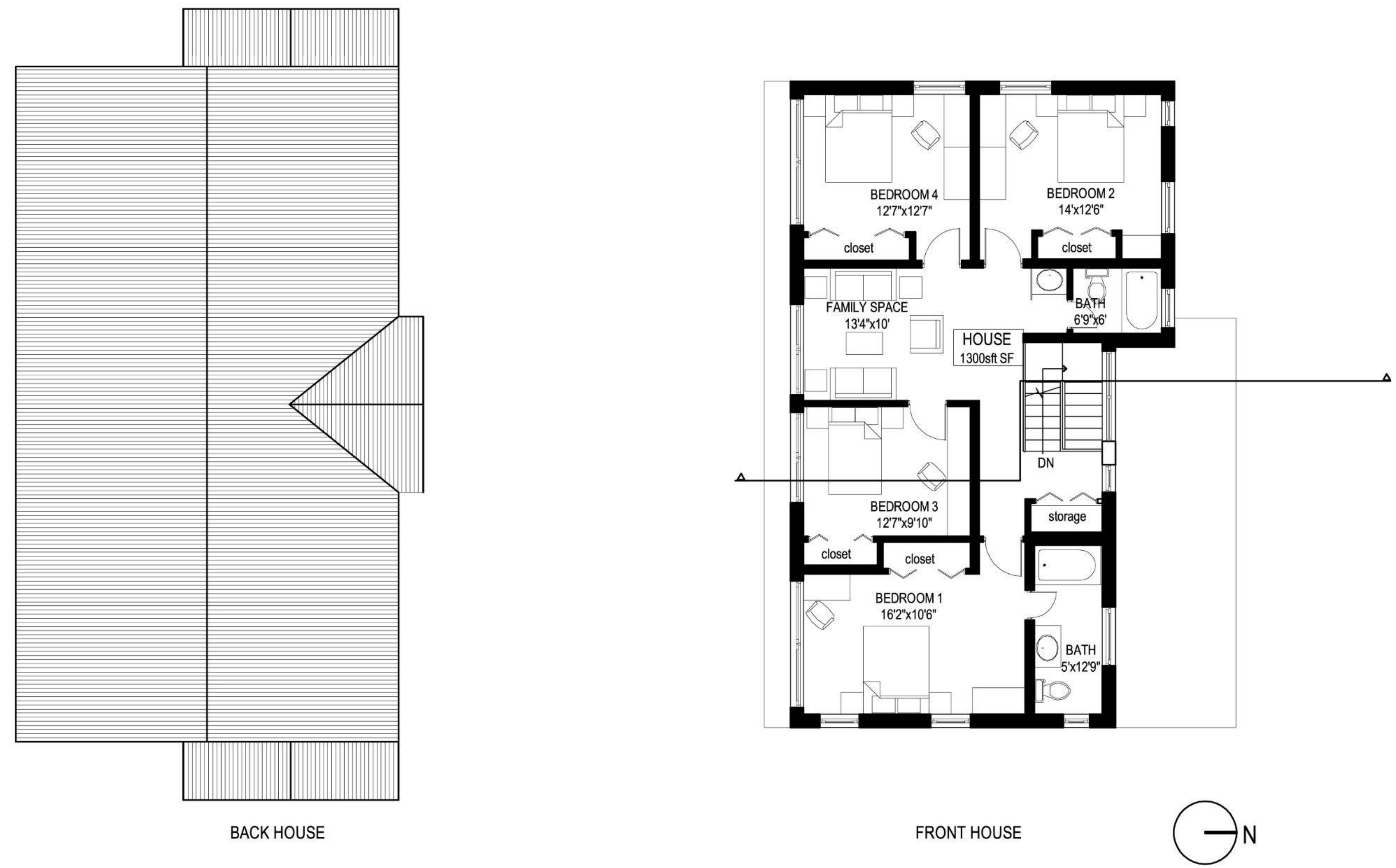


Figure 3.17 1a Basement Floor Plan

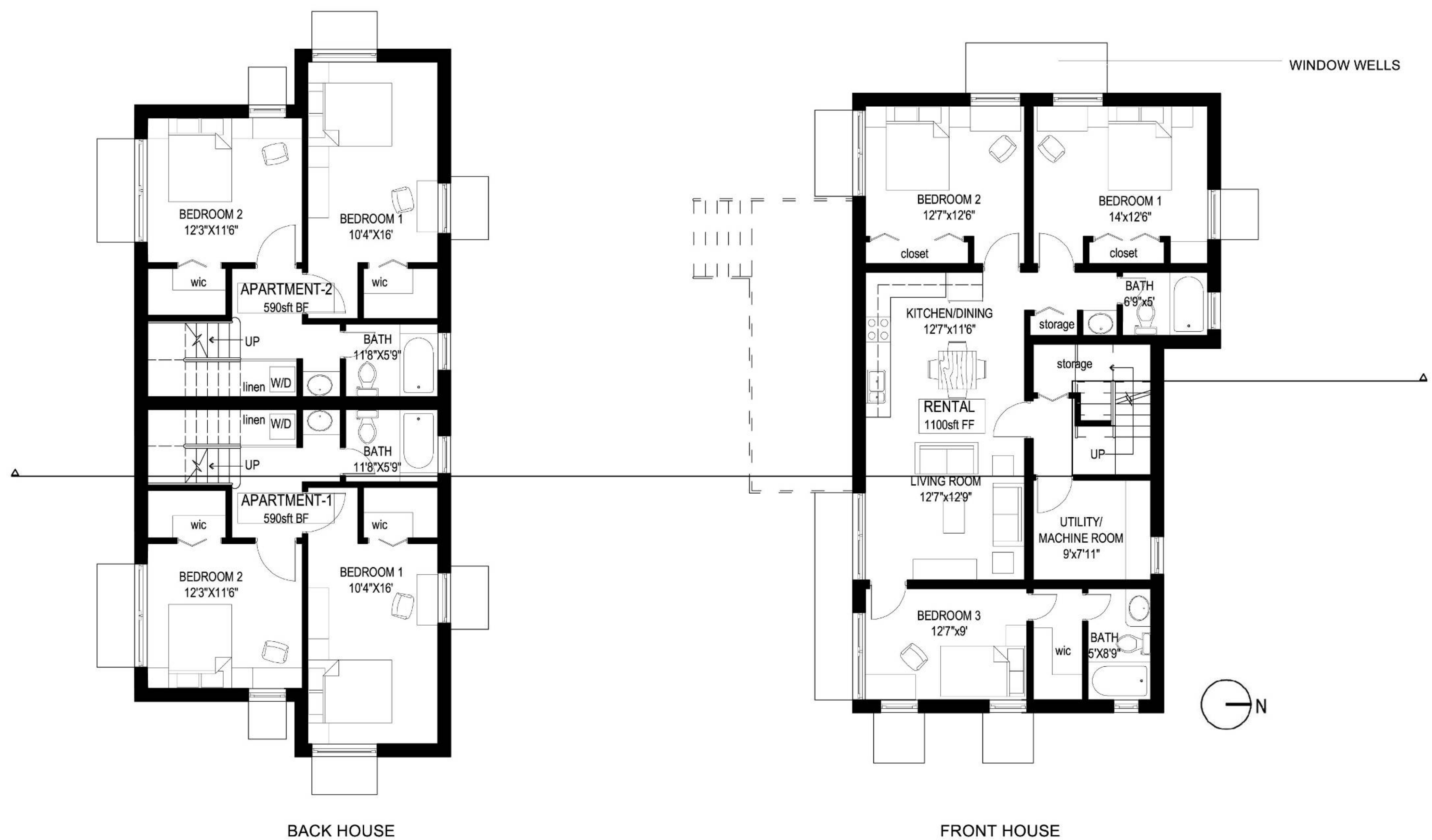


Figure 3.18 1a Section AA’

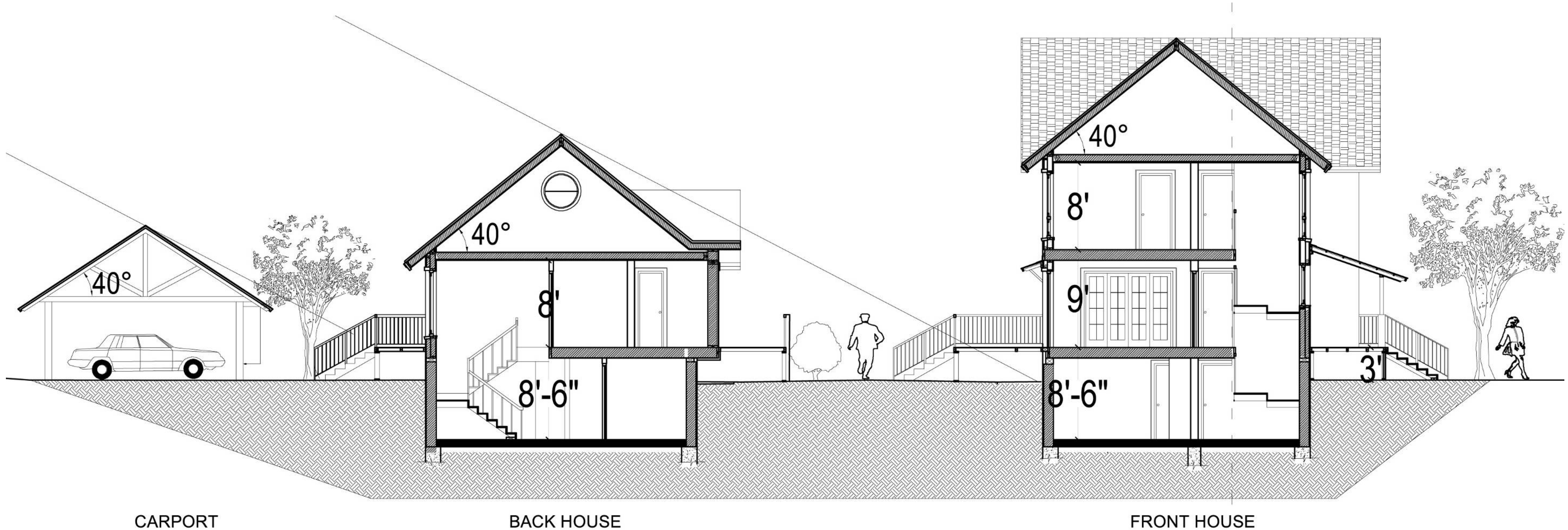


Figure 3.19 1a South and North Elevations

Figure 3.20 1a West and East Elevations

Type 1e House

The variation in this design is in the back house that is conceptualized as a one storey adaptable rental unit and hence can be used by disabled renters. The apartment could otherwise be occupied by a small family or a couple of students. Any front house design could be used in combination with a back house that has a patio and porch to its south with an accessible parking space. The total area of the back house is 1,075 sf. A front house with a tornado shelter is used in this arrangement to provide shelter when required since the back house is built on grade.

Figure 3.21 1e Location Plan

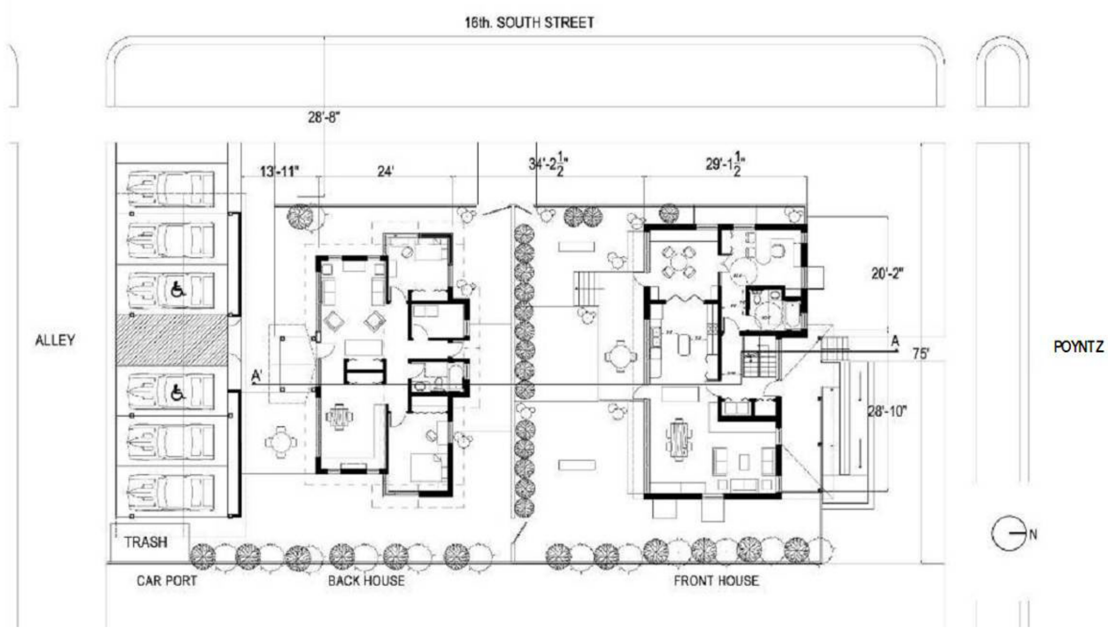


Figure 3.22 1e First Floor Plan

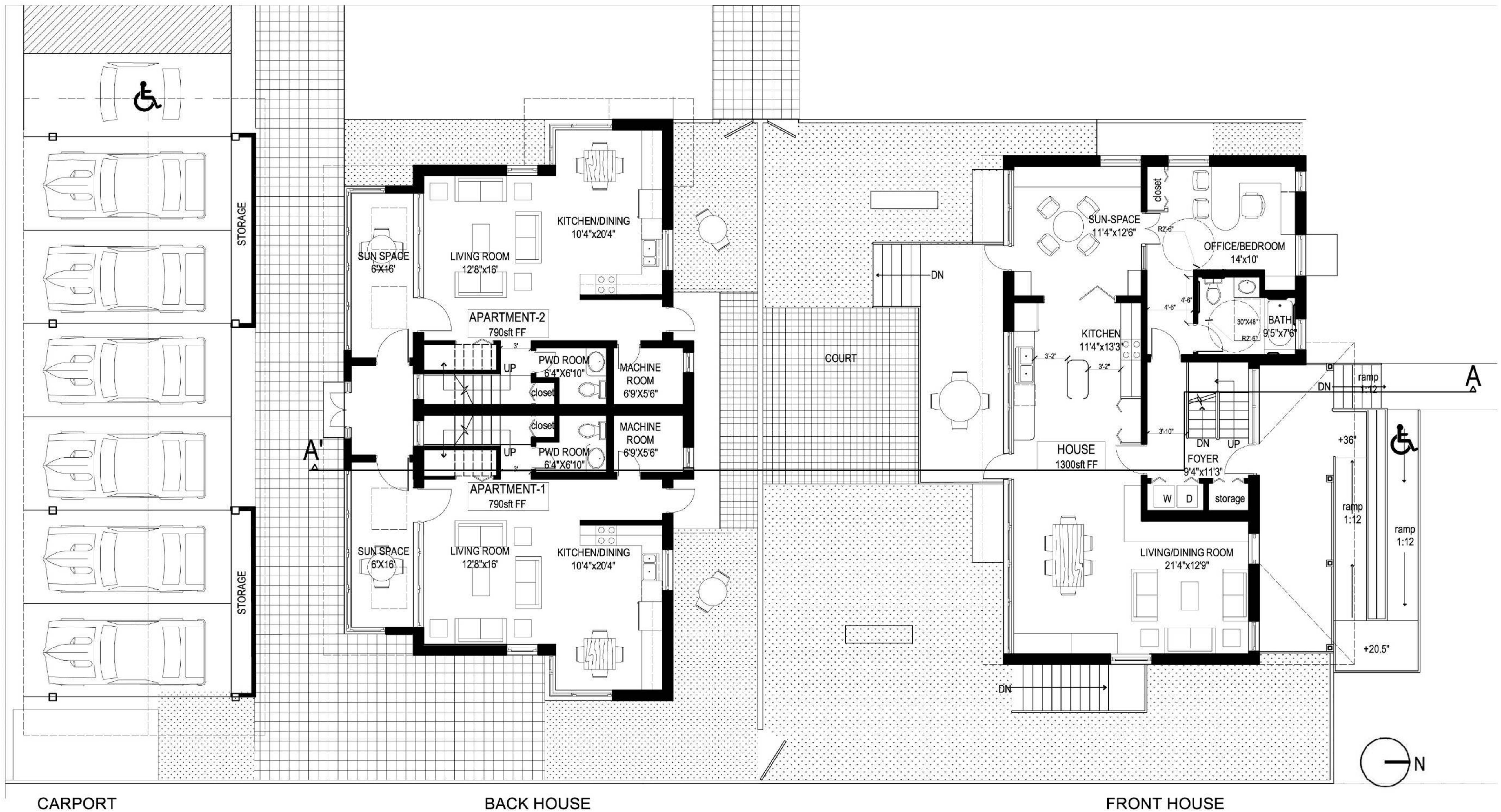
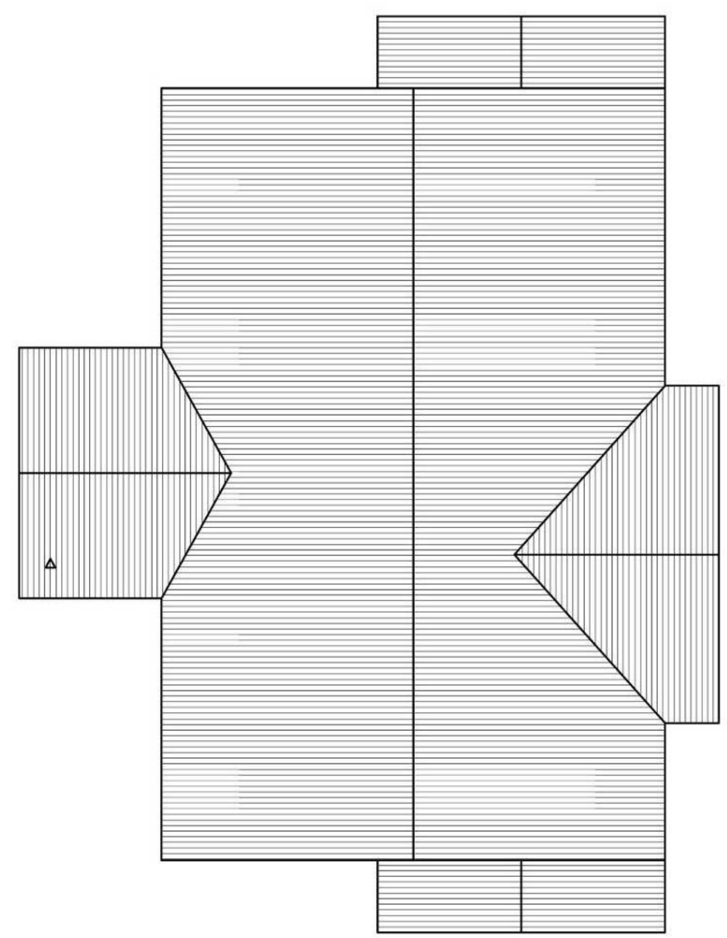
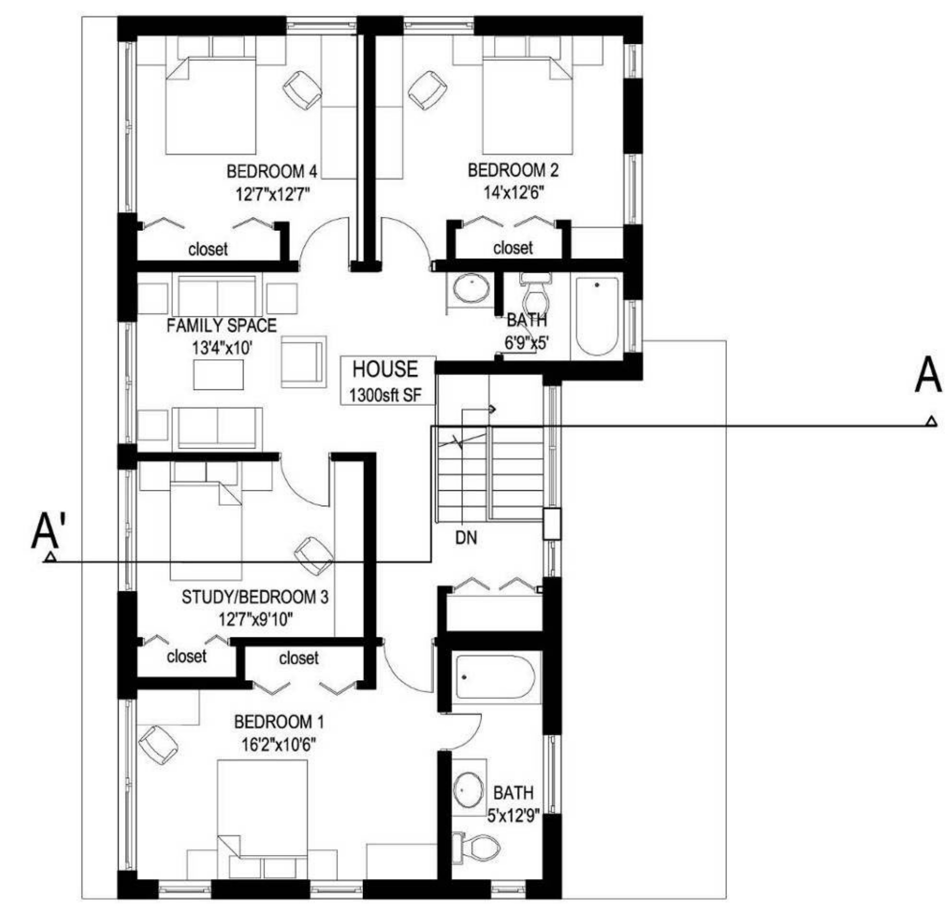


Figure 3.23 1e Second Floor Plans



BACK HOUSE



FRONT HOUSE

Figure 3.24 1e Basement Floor Plans

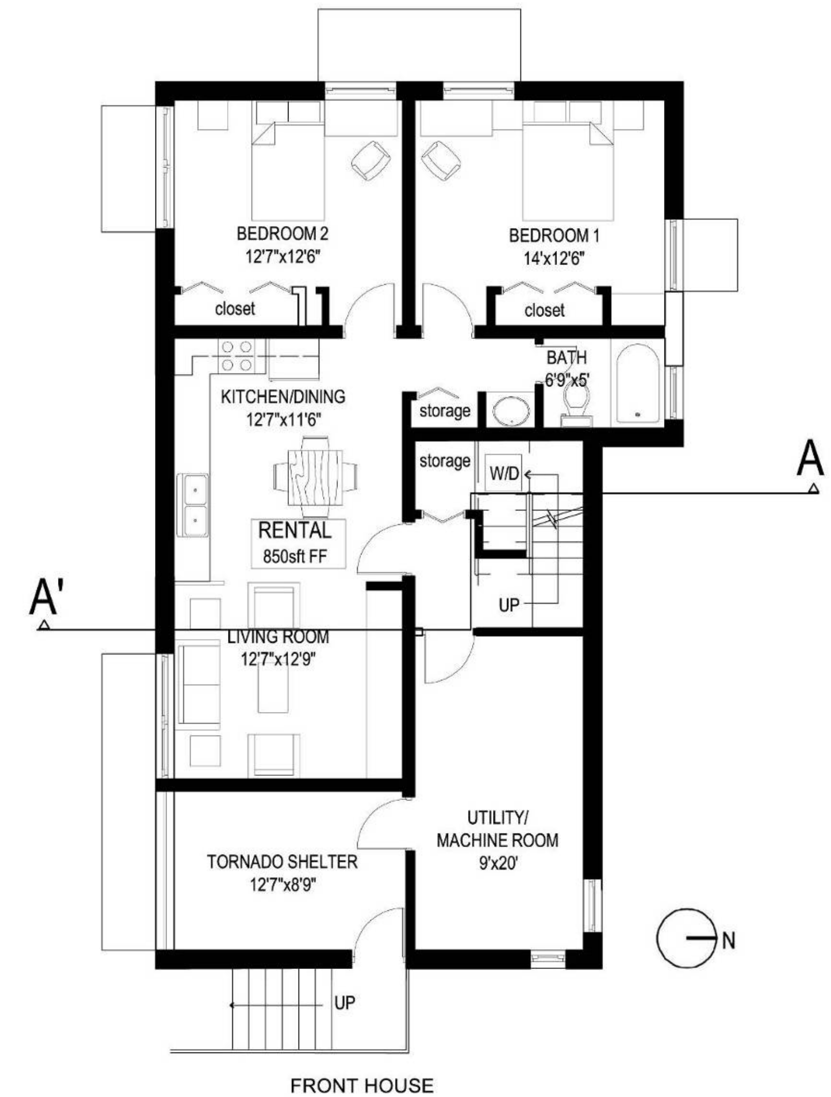


Figure 3.25 1e Section AA'

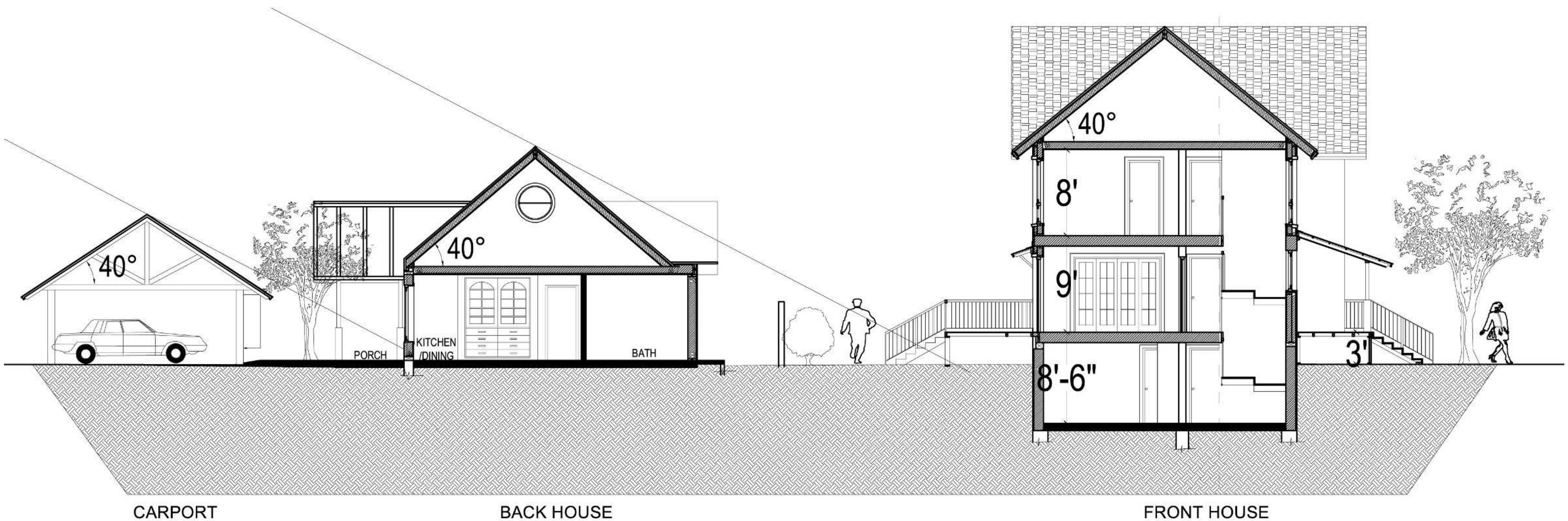
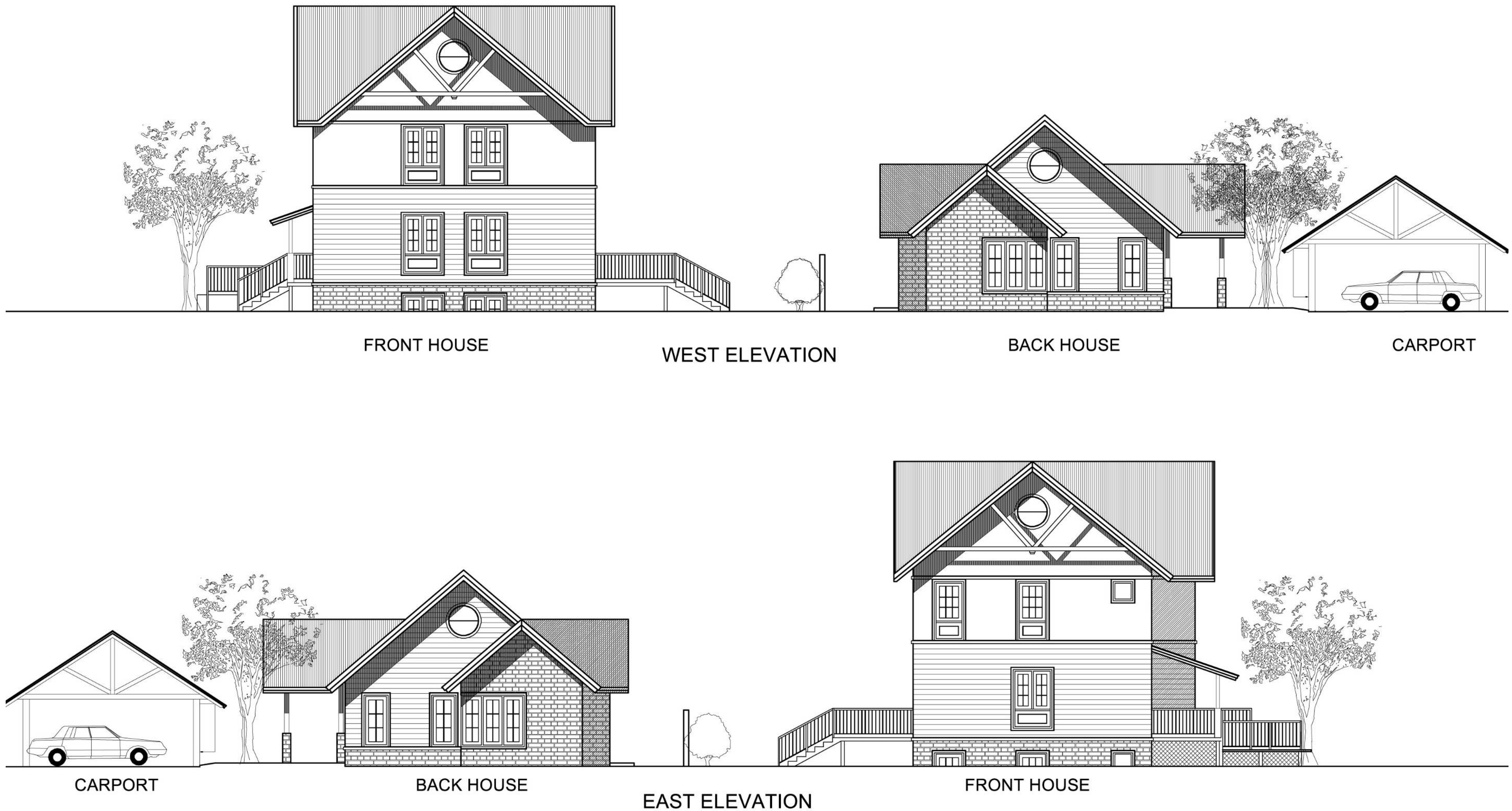


Figure 3.26 1e South and North Elevations

Figure 3.27 1e West and East Elevations



Type 2 Houses: Adaptable first floor of front house occupied by owner with basement, second floor and back house as rental units.

Four different variations of Type 2 housing units are presented. A description of this type of house has been provided earlier in this Chapter under Type 2 house. Type 2a house is described below.

Type 2a House

The front house in this case has a sun deck facing the south and the back house is built on grade and goes up two stories and has a sun space to the south. The first floor of the front house is made adaptable for the occupants with disabilities. The kitchen island in the front house is a movable island. Since the owners occupy only this floor the sun room can be used as a home office or a study. The home office in the previous design acts as the bedroom in this case and the rest of the unit remains the same. In the second floor, a door is added to make it a separate apartment for a young/starter family, a group of students or a sibling who has returned home and cannot afford to stay elsewhere.

The basement can be leased out similarly and it has a tornado shelter for the residents. Since there is hardly any change in the outer shell of the houses, the square footage remains constant. The flexibility is achieved by adding a door in the first floor entrance and by opening up a room to make one big living and kitchen space. These characteristics are seen in all the various designs of the Type 2 house options. The total area of the front house is 2,600 sf. inclusive of a 1,300 sf. first floor rental apartment. The basement apartment is 850 sf.

There is not much change in the back house and it is used primarily as a rental unit. It has a total area of 1,300 sf. for each apartment. All the designs in the matrix have storage space in the carport which also shields the back house from the light of the vehicles.

Figure 3.28 2a Location Plan

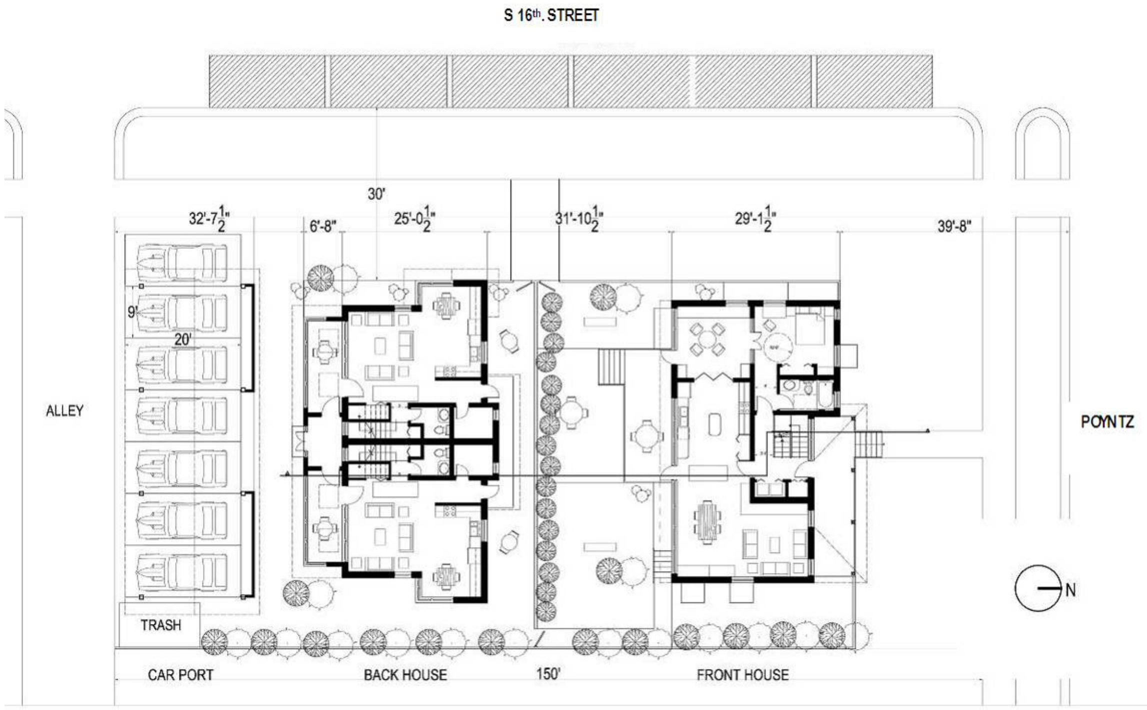


Figure 3.29 2a First Floor Plan

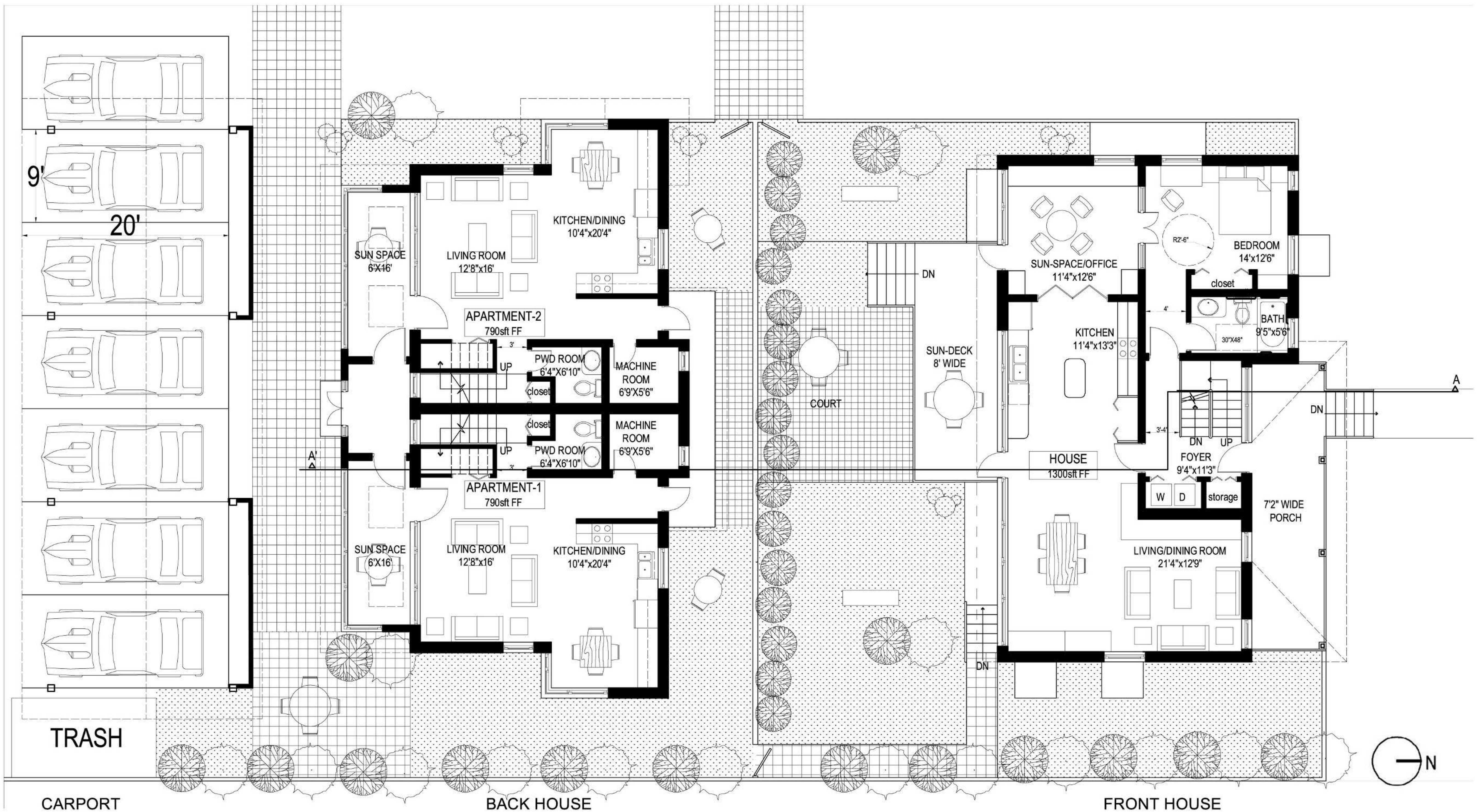


Figure 3.30 2a Second Floor Plan

Figure 3.31 2a Basement Floor Plan

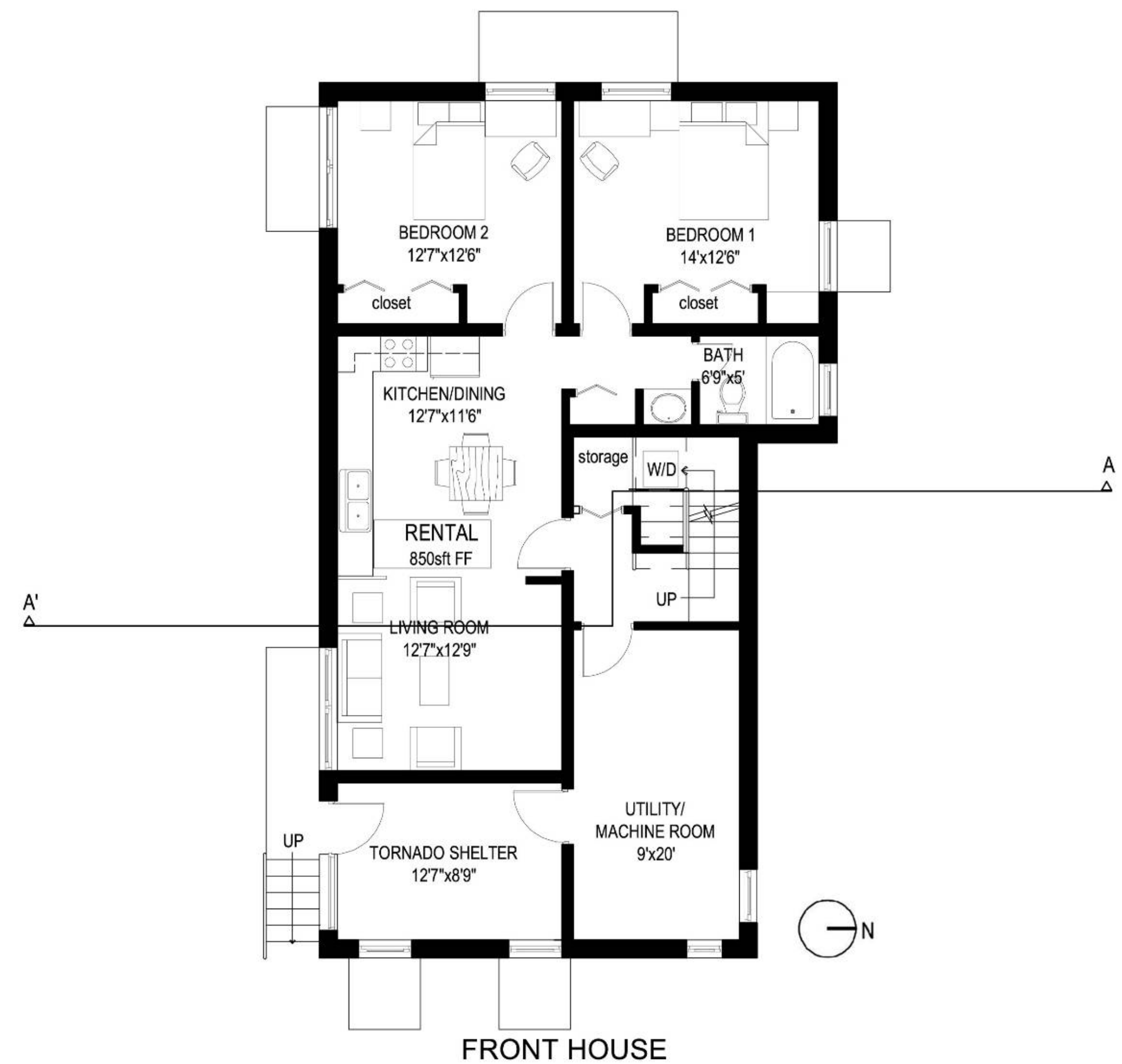


Figure 3.32 2a Section AA’

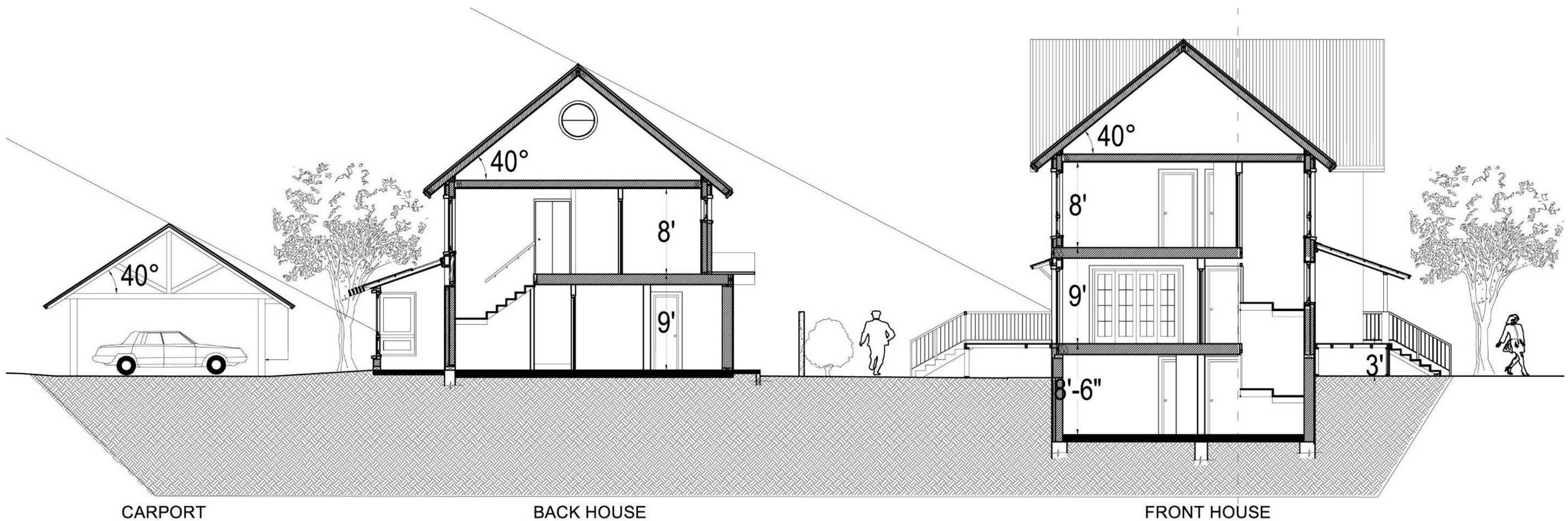


Figure 3.33 2a South and North Elevation

Figure 3.34 2a West and East Elevation

Type 3 Houses: Front house occupied by owner, with an adaptable studio apartment, basement and back house as rental units.

As seen in the case of Type 2 houses, Type 3 houses are divided into four types by the incorporation of architectural variants. The description and the documentation of the same are provided below:

Type 3b House

As described before, Type 3 houses accommodate a studio apartment in the first floor of the front house as will be seen in the various types which shall be described shortly. The studio apartment could accommodate an in-law or a teenager or could be conveniently leased out to a student. This apartment adds versatility to the house. This feature is explored in all versions of this house type. The design is achieved by closing off the door from the kitchen to the sun-room and thus isolating this portion of the house as a small separate apartment. The rest of the floors above grade are occupied by the owner and the basement is leased out.

The design has half a sun space in the front house and the back houses have a basement floor and a first floor. The floor area of each apartment in the back house is 1,230 sf. The studio apartment in the front house is 500 sf. with a 1,100 basement apartment and the rest of the owner occupied portion is 2,250SF.

Figure 3.35 3b Location Plan

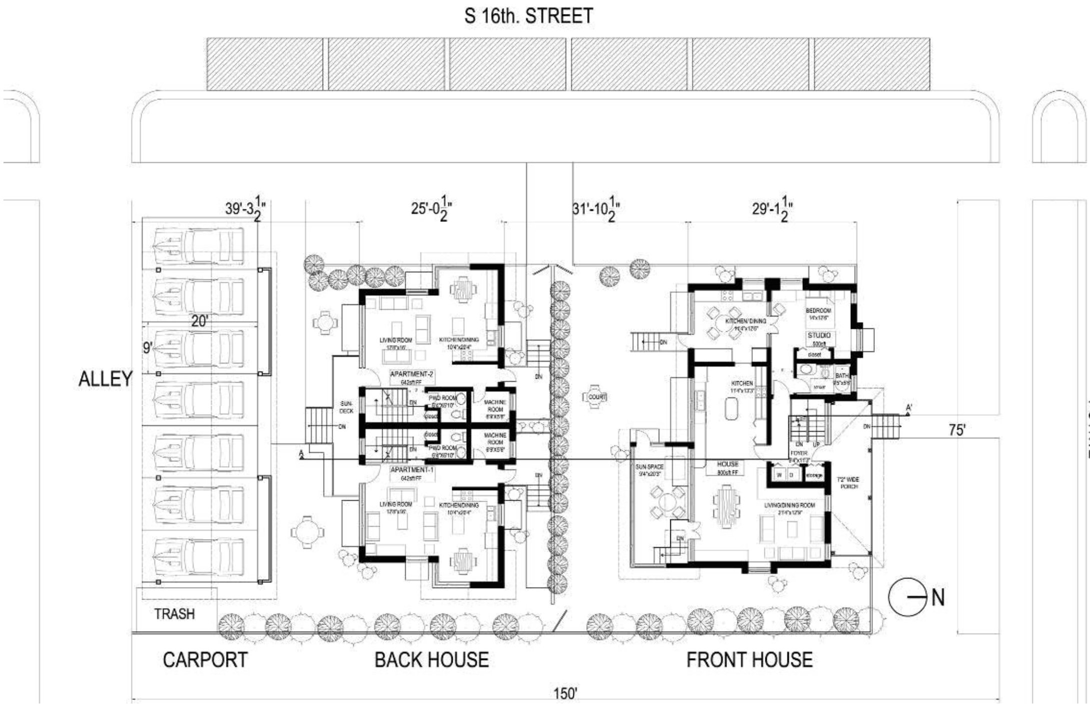


Figure 3.36 3b First Floor Plan

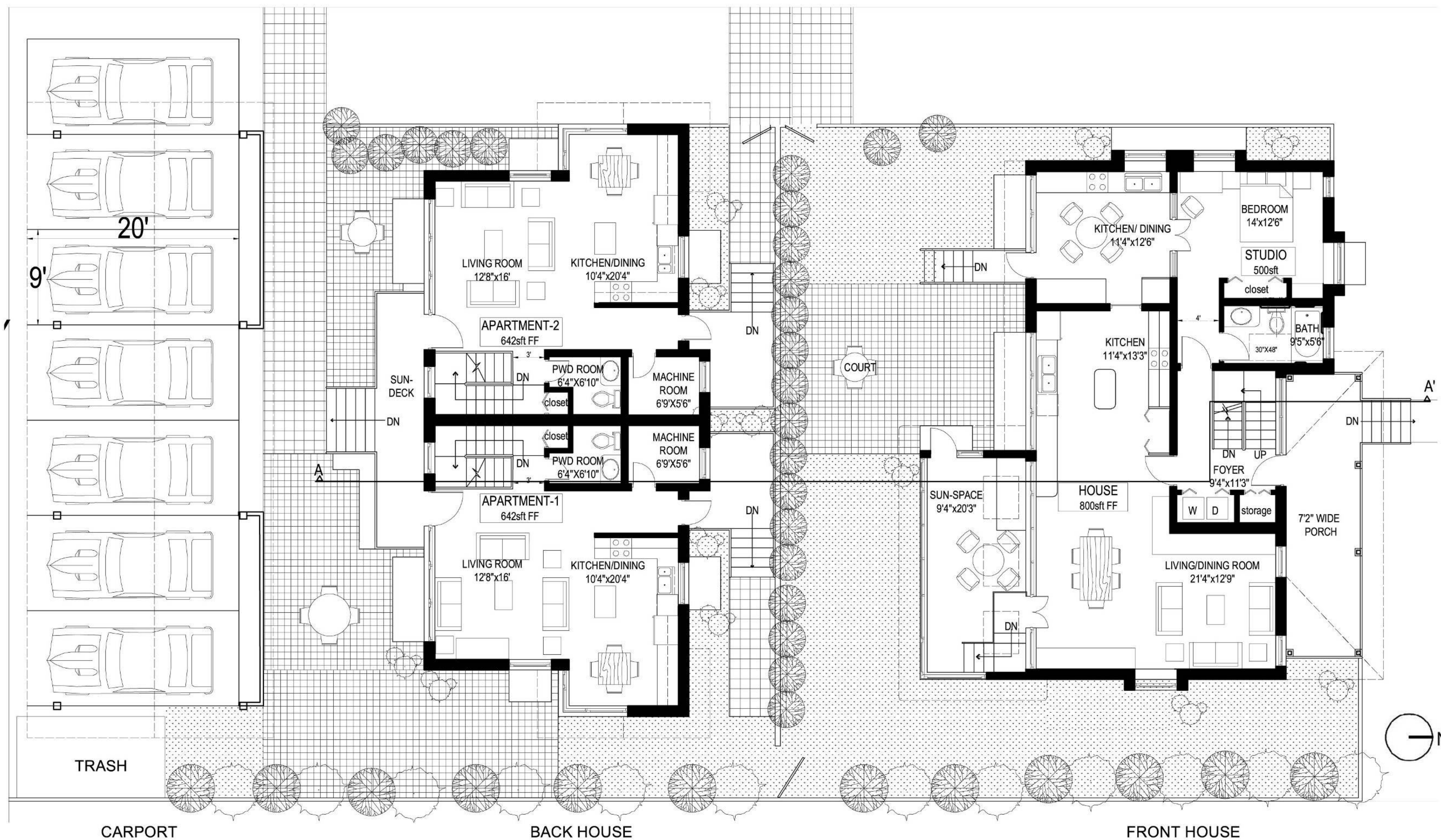


Figure 3.37 3b Second Floor Plan

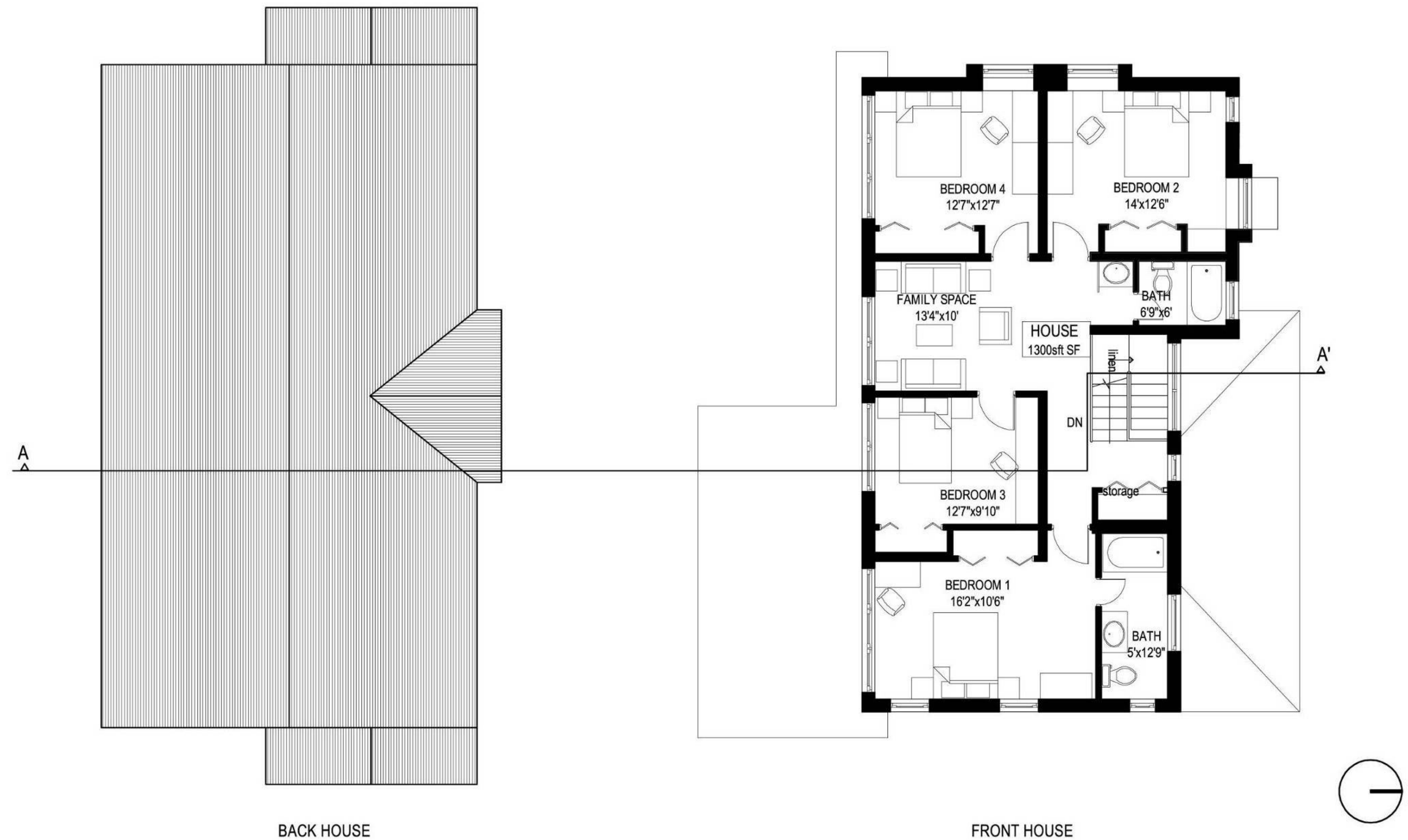


Figure 3.38 3b Basement Floor Plan

Figure 3.39 3b Section AA’

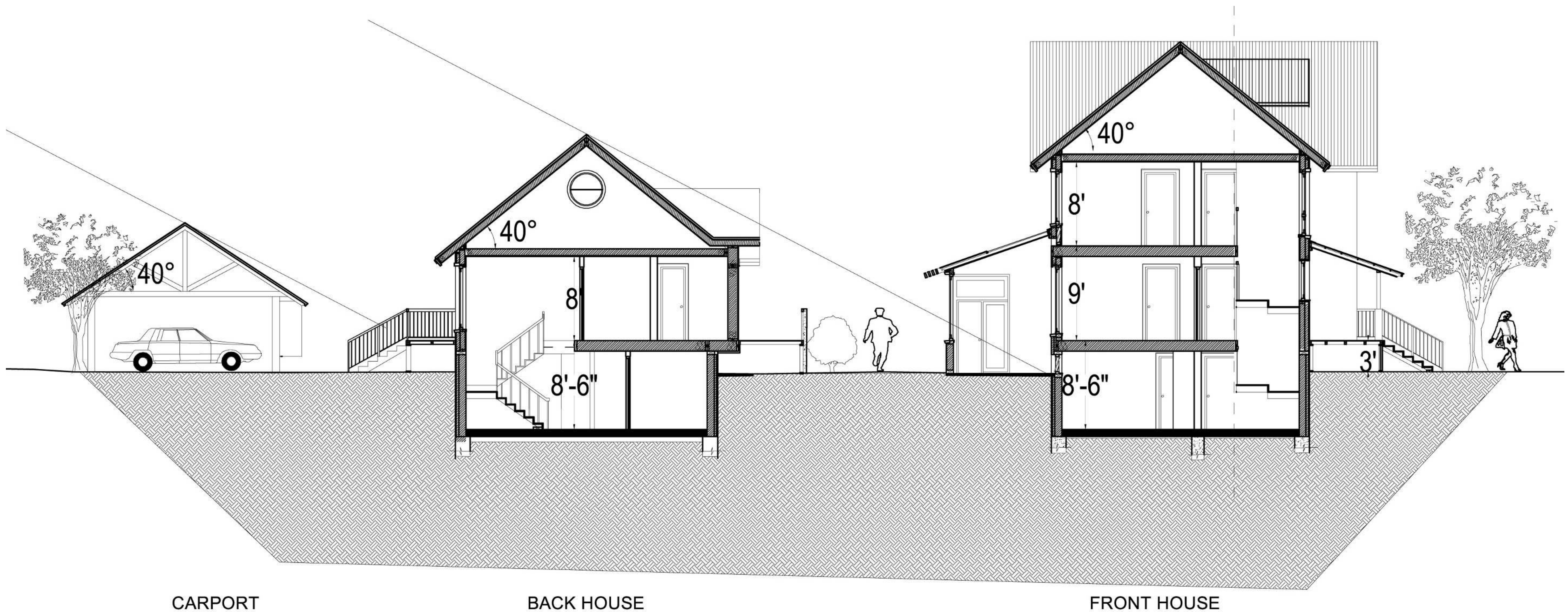


Figure 3.40 3b South and North Elevations

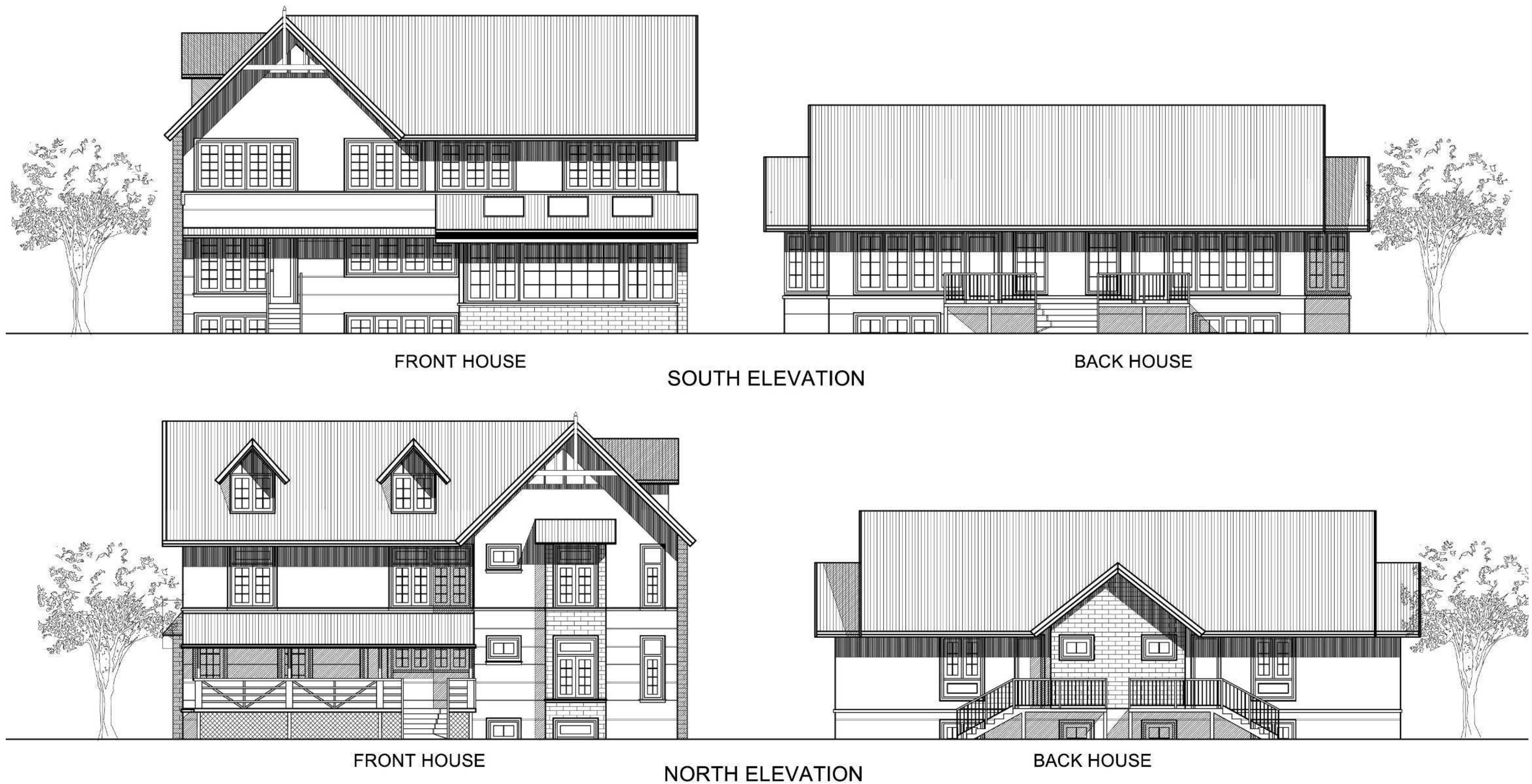
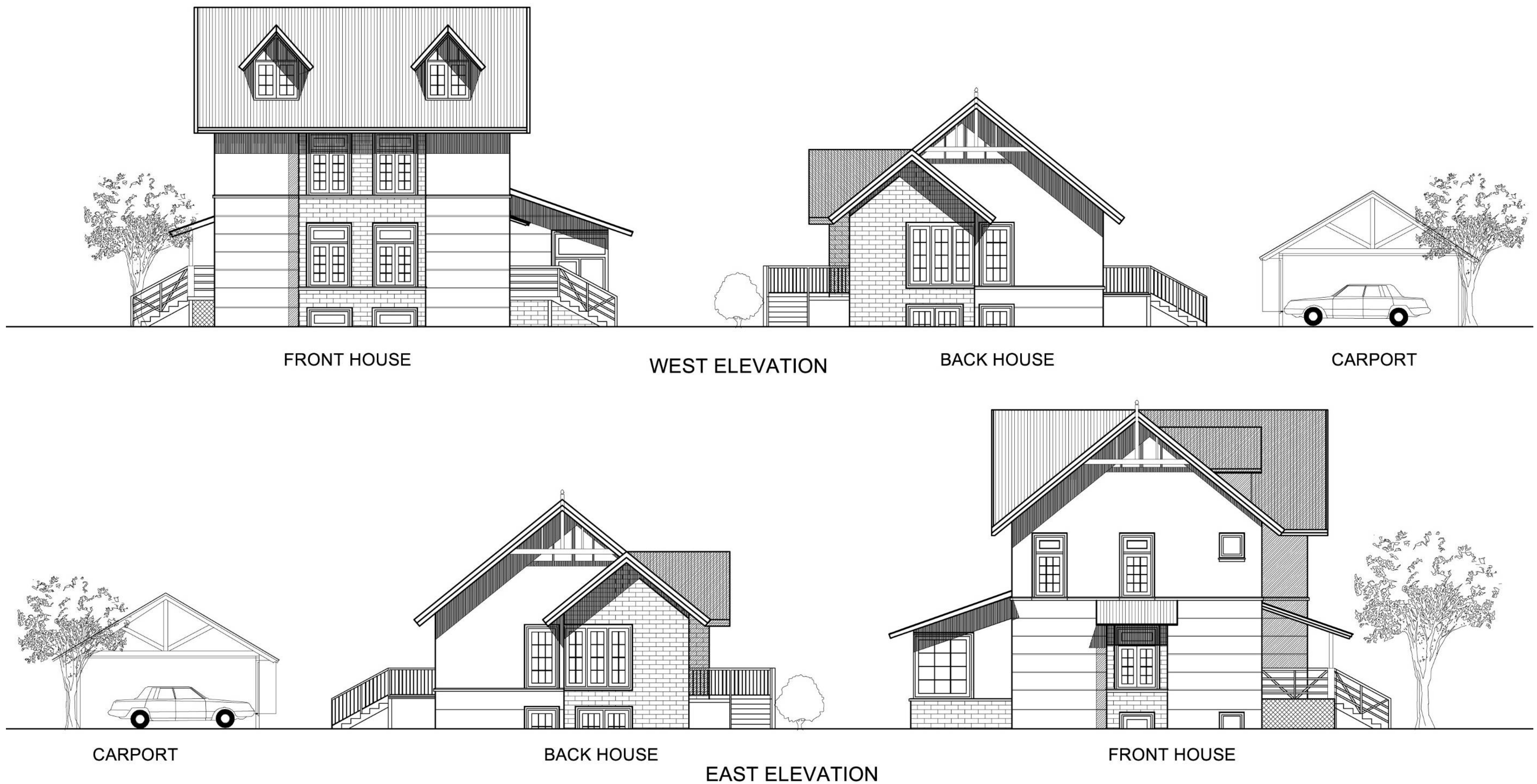


Figure 3.41 3b East and West Elevations



CHAPTER 4 - Energy Analysis

An independent study was conducted to supplement the thesis work. In view of the increasing global environmental concerns, this study was undertaken to achieve a 'zero energy threshold' for Type 1a house, within the design matrix presented in Chapter 3. Type 1a house proposes a front house with a home office occupied by owner, back house and basement as rental units. This option has a sun deck towards the south in the front and back house units. The back house has bedrooms in the basement with living/dining areas on the first floor.

A summary of this independent research is documented in this Chapter. Passive heating and cooling analysis was undertaken followed by simulations using eQuest and Energy-10 computer programs to analyze the design. Necessary changes in the design were carried out to achieve the zero- energy objective, while trying to maintain the integrity of the design of the house. Active energy systems for the design, building integrated photovoltaic cells and a geothermal HVAC system are also explored.

This Chapter is divided into four sections described as under:

i) **Passive Heating and Cooling Analysis:** This section describes the passive heating and cooling strategies used in the design alternative that served as the basis for the energy analysis.

ii) **Energy Simulation:** A brief description of the simulation software is followed by the results of the simulation. The various energy efficient measures used in the designs are described. The low-energy case achieved is compared with a reference or a baseline case to understand the energy savings after employing the energy efficient strategies.

iii) **Renewable Energy Systems:** A description of the renewable energy system and operation of such a system is provided in this section. The sizing of the system is also calculated.

iv) **Shading Device and Architectural Drawings:** This section describes the shading device designed for the house. Changes in the design of Type 1a house to achieve zero energy have also been discussed in this section.

Passive Heating and Cooling Analysis

As pointed out above, house Type 1a from the matrix was chosen so that a more elaborate energy analysis could be carried out to make this particular design option as energy efficient as possible. This section is an elaboration of the bioclimatic design strategies, discussed in Chapter 3, wherein certain rule-of-thumb calculations were established as the basis of design. More detailed performance estimates using Energy10 and eQuest, computer programs, are also presented. The book *Sun, Wind and Light* by G.Z Brown & Mark DeKay (2001) was used for the initial design. The workbook, *Bioclimatic Dwelling Design* by Gary J. Coates (2007) was extensively utilized to compute values for various factors that helped create a design that utilized ample amounts of passive heating and cooling thus decreasing load on energy intensive mechanical systems.

This study began with the calculation of the sizes of the windows and thermal mass in the South side of the house and then moved on to a calculation of heat loss and heat gain factors. Both the front and back houses were analyzed separately and the documentation for the same has is presented in the following pages.

The climatic data for St. Louis provided in the appendix of *Sun, Wind and Light* (p 310-313) was utilized for the heat loss and heat gain calculations since data for this city was readily available and its latitude is closest to that of Manhattan.

Front House

Following the steps described in the workbook by *Bioclimatic Dwelling Design* by Gary J. Coates (2007) and data from *Sun, Wind and Light* by G.Z Brown & Mark DeKay (2001) various calculations were carried out.

Table 4.1 Size of Solar Aperture on the South

1	Total Conditioned Floor:	3,900 sf	
2	**Total Solar Aperture :**	**741sf**	
3	Ratio of Solar Aperture/Floor Area :	0.19	
4	Estimated SSF (No Night Time Insulation) % :	21(low)	33 (high)
5	Estimated SSF (Night Time Insulation) % :	41(low)	65(high)

Thus if there is a solar collection area of 19% of the total floor area then the total solar savings fraction in heating the house is 21-33% if no night time insulation is used and 41-65% when night time insulation is used. (Brown 2001, p.249)

Table 4.2 Direct Gain and Thermal Mass Area

	Area(sft)	% of Solar Aperture
Direct Gain (windows)	**445**	**60%**
Thermal Mass(floors)	**296**	**40%**
Total	**741**	**100**

The calculations suggested that the total area of the windows on the south façade be 445 sf with a total thermal mass of 296 sf. The total area of windows finally provided after the final simulations was 445 sf which is equal to that suggested by the calculations in Tables 4.1 and 4.2. Thermal mass was achieved by providing clay tiles in the sun room, dining room and kitchen floors as well as in the floor of the family room in the second floor.

The recommended R-values for the various building components are provided in Table 4.3 (Brown 2001, p. 214 & p. 272). The same R values were later used in the computer simulations too.

Table 4.3 Recommended 'R' and 'U' values for the building components

	Opaque Walls	Earth Contact Walls	Roofs	Windows
R-Value	23	43	49	3.1
U-Value (1/R)	0.04	0.023	0.02	0.33
Thickness	6"	-	16"	

Heat Gain was calculated using the following methodology as described in Tables 4.4, 4.5 and 4.6 and Figure 4.1:

Table 4.4 Relation between area of opaque, insulated building envelope and total glazing (non-south) area

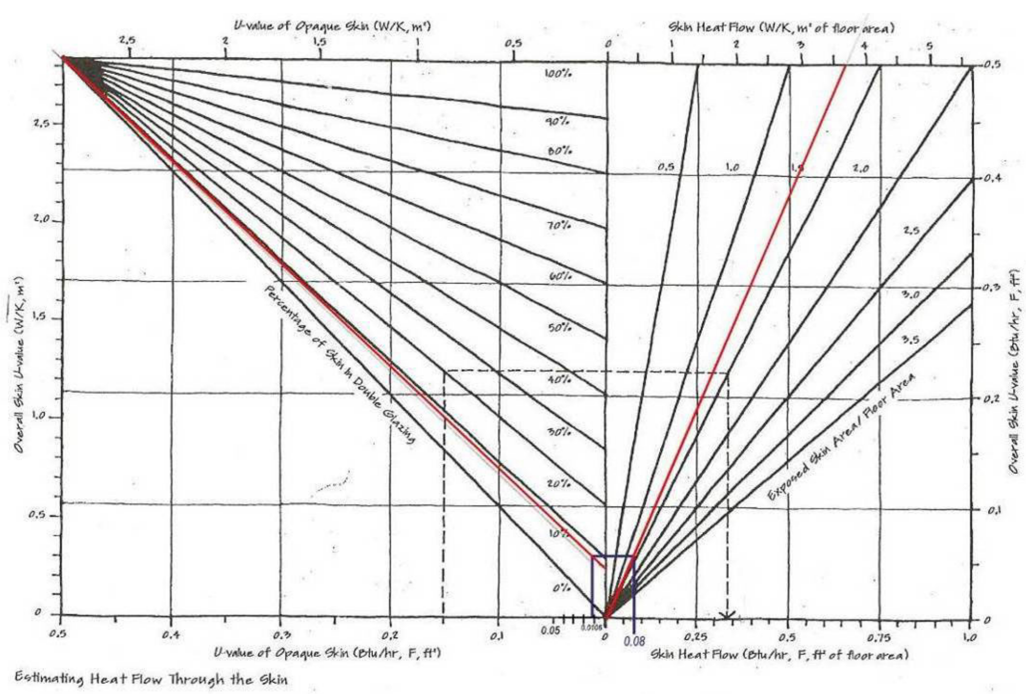
a	Total Area of (opaque and glazed) building envelope (exclusive of South wall)	5,103 sf
b	Total Area of glazing exclusive of South Wall	301 sf
c	% of Total Envelope (exclusive if South Wall) in glazing (b/a)	9.30%
d	Total Area of opaque building envelope exclusive of south wall (a-b)	4,802
e	% of Total Envelope in opaque Building Envelope (d/a)	95.70%

Table 4.5 Area of Weighted Average U-Value of Opaque Skin

	Area (A in sft)	% of Total Opaque (A/d from table 4)	R-value	U-Value (1/R)	%XU
Opaque Roof	1,928	0.4	49	0.02	0.008
Earth Contact Wall (basement)	936	19%	43	0.02	0.0038
Opaque Wall	2538.3	0.52	23	0.04	0.021
Area Weighted Avrage U-Value of the Opaque Skin					0.0106

Figure 4.1 Skin Heat Flow Graph

(Coates 2007, p 2-24)



Finally a compilation of the calculation above was done to arrive at the total heat loss of the building. This is presented in Table 6.

Table 4.6 Building Heat Loss Calculation

a	Percentage of (non-South) Exposed Skin in Double-Glazing (Answer c in Table 4)	9.30%
b	Exposed Skin Area/Floor Area (Answer a in Table 4/floor area)	1.28
c	**Skin Heat Flow (Btu/hr,F,sf. of floor area)(from fig.1)**	**0.008**
d	**Infiltration Heat Loss (Btu/hr,F,sf. of floor area)**	**0.09**

Thus the Heat Loss can be calculated as:

Skin Heat Flow (from Table 6) + Infiltration (from Table 6) = 0.098 Btu/hr,F,sf floor area.

The Total Heat Loss = 0.098 X 24 hrs/day= 2.35 Maximum Heat Loss (Btu/DD,sf.)

The Total Heat Loss of the building is less than 5.6 Btu/DD,sf , which is the maximum allowable heat loss for a passively soar heated building (exclusive of south wall) in a region with annual degree days between 3000-5000. (Coates 2007, p 2-22)

Similarly the heat gained through the building envelope was calculated which is documented in Appendix C. Total heat gain was 6.878 Btu/hr,sf or 1.95 Watts/ ft^2.

Back House

Tables C.1-C.6 and Figure C.65 in Appendix C show the passive solar heat calculations for the back house units. According to the calculation, the total amount of south glazing provided is 131 sf and the thermal mass was 94 sf.

The total amount of heat loss is 2.25 (Btu/DD,sf.) which is less than 5.6 Btu/DD,sf. , the maximum allowed heat loss for a passively soar heated building (exclusive of south wall) in a region with annual degree days between 3000-5000. (Coates 2007, p. 2-22) The total heat gained by the structure is 7.47 Btu/hr,sf or 2.11 Watts/ sf.

In this manner the front and back house designs were updated so that they positively responded to the passive solar heating and cooling strategies.

B. Energy Simulation

The next step included detailed analysis of the design using computer simulation techniques to calculate energy consumption of the house. Energy simulation largely involved the use of two different computer programs, Energy-10 version 1.8, made available by the National Renewable Energy Laboratory's (NREL) Center for Building and Thermal Systems, and eQuest-3.6 by Energy Design Resources. Results of computer simulations illustrating the energy performance of the buildings are outlined below.

Since these programs were designed mainly for analysis of structures in the state of California, there are some considerations in the calculations that default to values for California. This could possibly result in some minor discrepancies in the analyses for the climate of Manhattan, KS.

E-10 Simulation

Energy-10 resulted from the collaborative efforts of NREL Center for Building and Thermal Systems, Sustainable Buildings Industry Council (SBIC), Lawrence Berkeley National Laboratory, and the Berkeley Solar Group. It is user friendly and can help a designer identify the most efficient energy conservation measures for a building leading to a reduction of 40-70% of the building's energy consumption with nominal increase in construction costs. It can be used in the simulation of commercial or residential buildings with areas up to 10,000 sf, having up to two thermal zones. The accuracy of this software has been verified by the BESTEST procedure which was also developed by the NREL (http://www.nrel.gov/buildings/energy10.html: 4/10/'08).

Version 1.8 Energy-10 can size photovoltaic panels as well as the solar domestic hot water module for the designed building with the specified number of occupants. This version also has a new library, 'ASHRAELIB', for specifications of construction standards to be followed as provided by 'ASHRAE 90.1-2004' (http:// www.sbicouncil. org/store/e10.php: 4/10/'08).

The software generated two cases from the data provided, one was the reference case and the other was the low energy case based on the integration of the energy efficient measures. It generated a complete year round energy analysis of the building which was quick and accurate. It also automatically performed a life cycle cost analysis that assisted in understanding the cost flow that could expected during the lifetime of the structure and also provided an estimate of savings due to the energy conservation measures.

Since there was no option for the use of a geothermal heating/cooling system, 'Fixed COP System' was used, which is similar to a geothermal system. The drawback of this software was that it could only be used for the initial design stages. Hence, one could not perform an in-dept simulation for a more detailed design since there were no options to do the same. However, it was a good tool to understand the way in which various energy efficiency boosting measures ranked and the ones that could potentially be used as part of a practical design solution.

Front House Energy-10 Simulation

In order to conduct energy consumption simulation for the front house using Energy-10, the basement apartment was considered as one thermal zone (zone 2) while the upper floors were conducted as a separate thermal zone (zone 1). The total number of occupants was assumed to be ten. Figure 4.2 shows the ranking of energy efficient strategies - strategies having a positive result have been used in the analysis. It is evident from the figure that building the house like an 'air-tight-box' is one of the most vital steps in achieving energy efficiency. Duct leakage and insulation also play important roles where-as the economizer cycle of the HVAC and daylighting play less important roles in energy efficiency. It is seen that thermal mass is not very important.

Figure 4.2 Ranking Energy Efficient Strategies

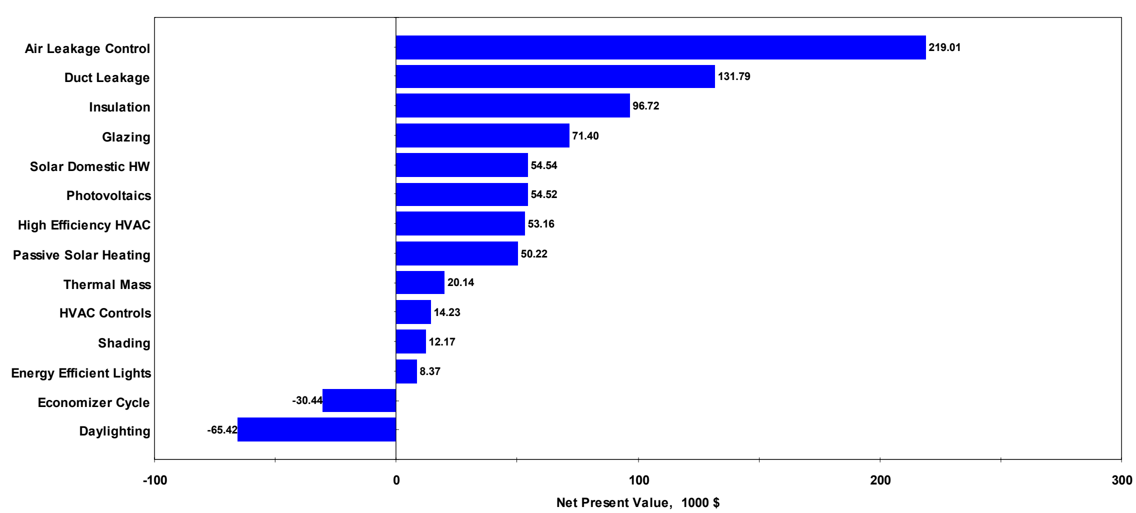


Table 4.7 gives a list of the energy efficient measures used by the low energy case. Fixed COP was used as this system represented the ground source heat pump. The recommended U value for the glazing in this zone is 0.33 (http://www.taunton.com /finehomebuilding/how-to/articles/understanding-energy-efficient-windows.aspx: 05/05/'08). The achieved U value of the proposed glazing was 0.31, which is close to the one recommended. Although shading was not one of the most important Energy Efficient Strategies, it has been used to shade the interiors in the summer. Thermal mass was not identified as an important measure, hence the mass recommended was not provided. However the thermal mass recommended by passive solar design calculation is provided in the final design.

Table 4.7 Energy Efficient Strategies for Low Energy Case

Energy Efficient Strategy		Descrpition
1	**Insulation**	**Walls**: 2X6 frame with sprayed polystyrene insulation. R=23.1
		Roof: Attic floor with blown polystyrene insulation. R=60.2
		Floor: Basement floor slab with carpet on rubber base. R=41.7
2	**Glazing**	4x6 double glazed, low-e glazing on all windows. U=0.31
3	**Photo Voltaics**	6.8kW system
4	**High Efficiency HVAC**	Fixed COP Heat Pump with setback
5	**Shading**	As recommended for 40° latitude

Figure 4.3 and Figure 4.4 display the energy savings achieved by the use of the above energy efficient design strategies. It can be seen that there is almost a 60% reduction in the annual energy use for the low energy case in comparison to a reference case which is simulated by means of the AHSRAE standards. Consequently there is a major reduction in the cost of energy for the low energy case. Since electric heating was used in the reference case the cost of fuel is zero. However, the electrical consumption of the low energy case is only 2kWh which is 8 kWh less than the reference case shown in Figure 4.3. Figure 4.4 shows a considerable reduction in heating costs due to the use of the geothermal system (Fixed COP). Cooling costs are also reduced by nearly 50% in comparison to the reference case.

Figure 4.3 Annual Energy Cost

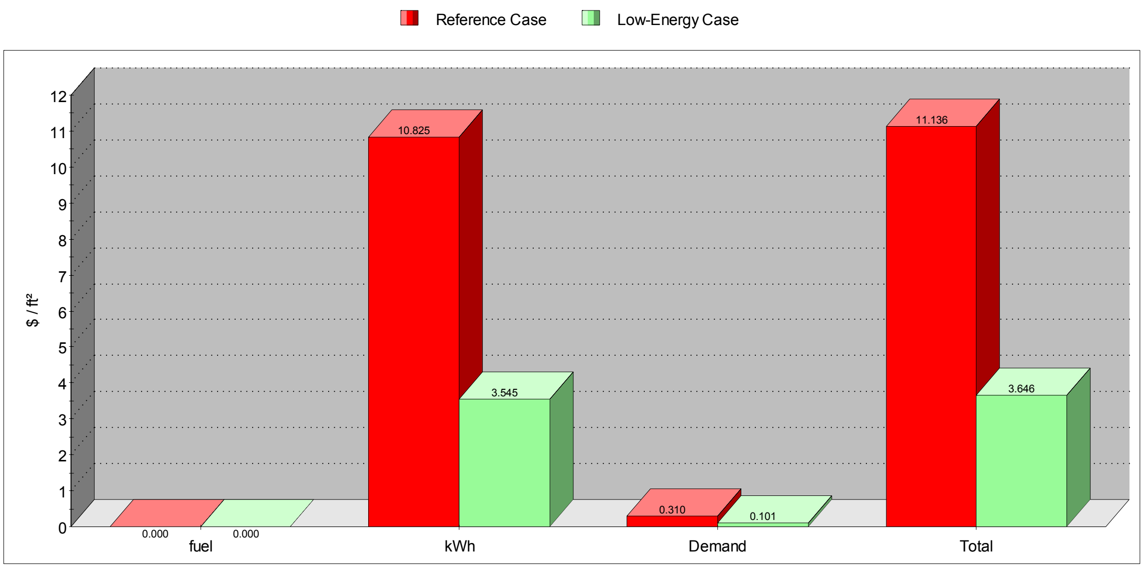
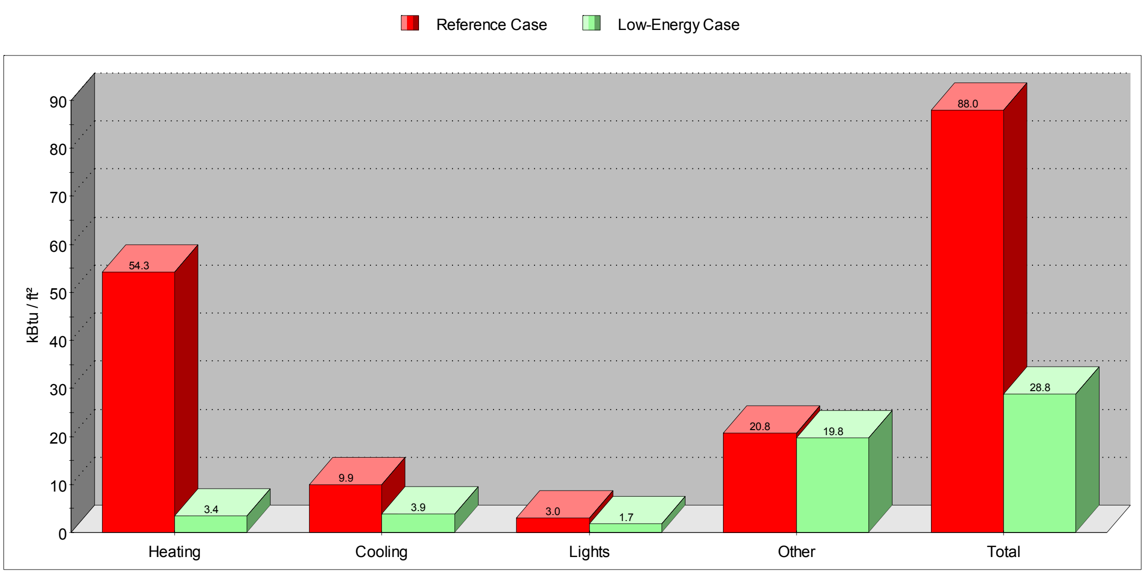


Figure 4.4 Annual Energy Use



Tables C.7 and C.8 in Appendix C describe the building envelope and HVAC specifications of the low-energy building. The size of the PV system is discussed in Table C.9 in Appendix C. The size of the PV system for the front house was calculated to be 6.8kW.

It can be concluded that a higher level of energy efficiency has been achieved by the low-energy case, as summarized in the preceding pages. Up to 60% savings in energy consumption is achieved in comparison to a standard house (reference case) built following the ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) standard of construction.

Back House Energy-10 Simulation

The simulation result of the back house is included in Appendix C in Figures C.66 and C.67. Energy efficient measures used for the front house were used in this case also. They depict a total of 50% energy consumption savings in comparison to a reference case. The same materials as used in the front house were used for the simulation of the back house as well. The total capacity of the photovoltaic cells was derived as 3.4kW systems for each backhouse apartment. The same has also been discussed in the section on photovoltaic systems.

eQuest Simulation

eQuest Version 3.6 was used to run simulations on the same design that was used as the basis of the Energy-10 simulation. This was done to reinforce/validate the findings of Energy-10 and also to gain experience in using yet another simulation tool.

eQuest was designed by Energy Design Resources, and employs a simulation 'engine' equivalent to DOE-2, albeit with additional capabilities. eQuest is a software that is much more comprehensive and can be used both in the schematic design phase as well as in the case of more complex designs. The software has a simple user interface with a multitude of tools to evaluate the energy consumption of proposed designs.

The software does not, however, automatically generate a reference/baseline case as in the case of Energy-10. Instead, one needs to specify and develop a base or a reference case and then build upon it to simulate a low-energy case. This procedure was followed in this study, whereby a reference case was generated using ASHRAE standards. Based on this, a low-energy case is developed to analyze the energy efficiencies achieved by the proposed design. The specifications provided in Energy-10 were used to develop both the reference and the low-energy case.

eQuest provided an option for the use of Geothermal HVAC which was named as 'ground source heat pump'. The following pages provide graphs as well as a brief description of the results from this simulation. It is evident that the projected final savings are comparable to the results achieved in the case of Energy -10 simulation. The strength of this software lies in its capability to generate a 3-D image of the building being analyzed. This enables one to create a 3-D model as close to the actual design as possible and thus obtain a more realistic simulation.

Front House eQuest Simulation

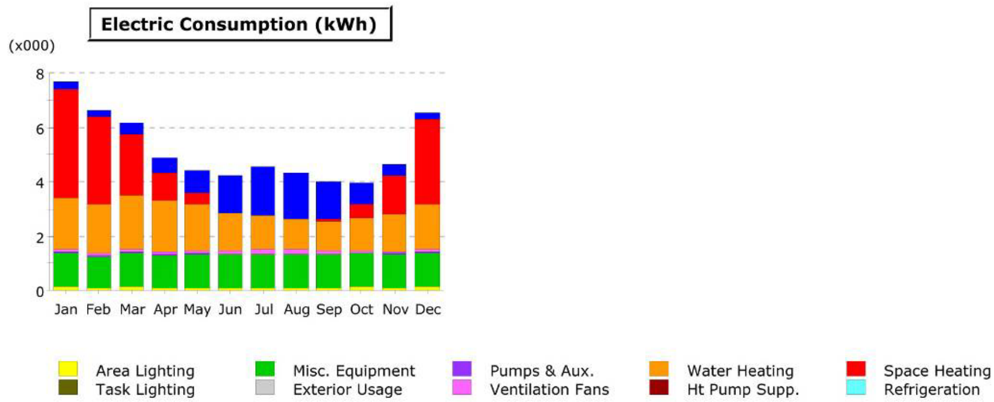
The simulation performed on eQuest was more comprehensive than that done on Energy-10 with more input fields and wide-ranging simulation options. The house was divided into two thermal shells and the HVAC served each shell separately. The first shell was the upper house and the second was the basement. Table 4.8 shows the comparison between the energy efficient measures used to generate the reference case and the low-energy case for this analysis. This Table also outlines the major energy efficient measures used for this simulation.

Table 4.8 Comparison between Energy Efficient Measures for Baseline and Low-Energy Case

Energy Efficient Strategy		Baseline Case	Low-e Case
1	**Insulation**	**Walls**: 2X4 frame with batt insulation. R=19	**Walls**: 2X6 frame with sprayed polystyrene insulation. R=23.1
		Roof: Attic floor with batt insulation. R=30	**Roof**: Attic floor with blown polystyrene insulation. R=49
		Floor: Basement floor slab (4") . R=5	**Floor:** Basement floor slab (4") with carpet with fiber pad R=10
2	**Glazing**	Double clear tint glazing on North, South, West and East Windows	South,West and East Walls: Double low-e glazing. Air filled.
			North Glazing: Double clear glazing
3	**HVAC**	Electric DX Coils with an efficieny of 9.7	Ground Source Heat Pump with setback and an efficiency rating of 10.00
4	**Shading**	No shading device	3' overhang on West, South and East windows

An estimation of the energy consumption of the baseline case and low-energy case is shown in the Figures 4.5-4.6. The numbers are greatly reduced in the low-energy case. The baseline case consumes about 61,992 kWh of energy annually whereas the low-energy case has an energy consumption of 39,940 kWh. Much of this saving is attributed to the considerable reduction in the heating costs. Domestic water heating has also been simulated. However, it may be pointed out here that a continuous supply of hot water via a geothermal unit all year round would further decrease the energy consumption.

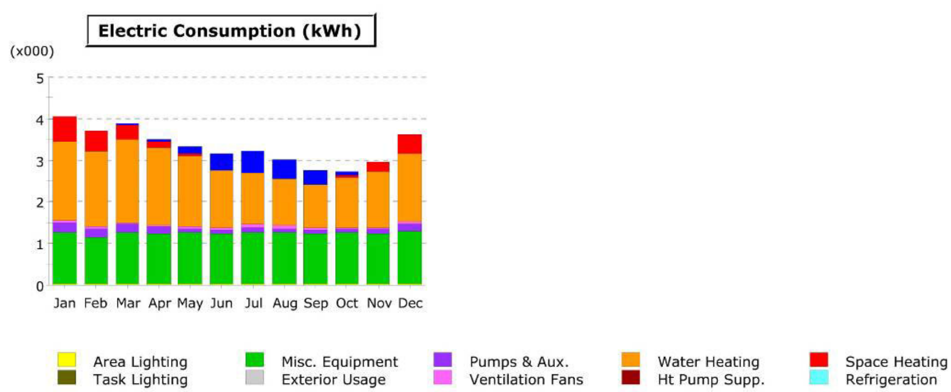
Figure 4.5 Energy Consumption of Baseline Case



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.26	0.27	0.42	0.55	0.85	1.40	1.77	1.66	1.37	0.81	0.41	0.20	9.97
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	3.99	3.18	2.25	1.04	0.41	0.00	0.00	0.01	0.11	0.46	1.44	3.16	16.06
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	1.88	1.81	2.00	1.88	1.71	1.38	1.24	1.11	1.04	1.20	1.38	1.64	18.27
Vent. Fans	0.09	0.08	0.08	0.08	0.10	0.15	0.18	0.17	0.15	0.11	0.07	0.07	1.33
Pumps & Aux.	0.07	0.06	0.05	0.02	0.01	0.00	-	0.00	0.01	0.02	0.05	0.07	0.36
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	1.24	1.13	1.25	1.20	1.24	1.21	1.24	1.24	1.20	1.24	1.20	1.25	14.64
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.13	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.13	1.37
Total	7.66	6.64	6.16	4.88	4.43	4.25	4.54	4.30	3.99	3.96	4.66	6.52	61.99

Figure 4.6 Energy Consumption of Low-Energy Case

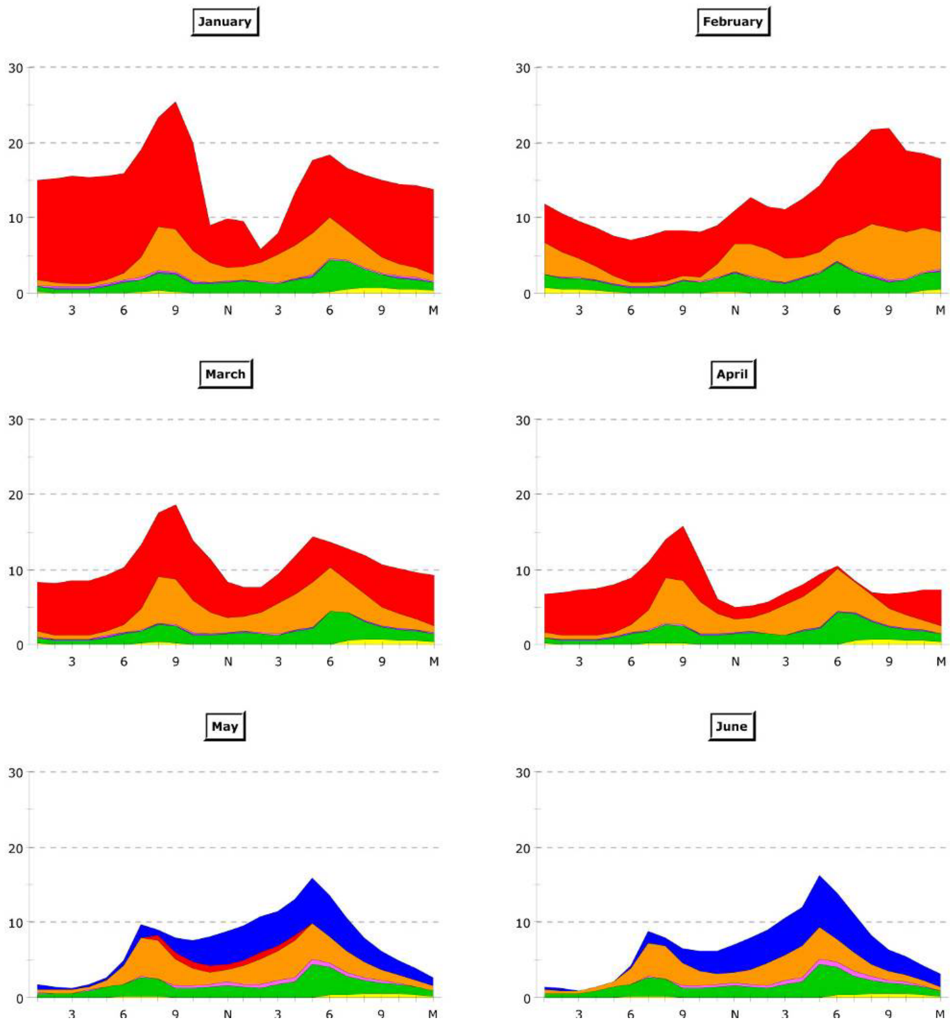


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.00	0.00	0.02	0.07	0.18	0.40	0.53	0.46	0.32	0.10	0.01	-	2.10
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.61	0.49	0.34	0.14	0.05	0.00	-	0.00	0.01	0.06	0.20	0.47	2.36
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	1.88	1.81	2.00	1.88	1.71	1.38	1.23	1.10	1.04	1.20	1.38	1.64	18.25
Vent. Fans	0.08	0.07	0.05	0.03	0.04	0.07	0.10	0.09	0.06	0.03	0.03	0.06	0.71
Pumps & Aux.	0.20	0.18	0.18	0.17	0.09	0.08	0.10	0.09	0.08	0.07	0.11	0.18	1.55
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	1.24	1.13	1.25	1.20	1.24	1.21	1.24	1.24	1.20	1.24	1.20	1.25	14.64
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.35
Total	4.05	3.70	3.87	3.51	3.33	3.16	3.23	3.01	2.75	2.73	2.96	3.63	39.94

Finally, Figures 4.7- 4.8, depict the monthly Electric Peak Load profiles. The Figures show that the reference case consumes more energy, especially in the form of heating loads. As described earlier, a huge amount of energy is conserved by saving on the heating costs. Since, in the low-energy case, the building shell has been made much tighter and double low-energy glazing has been utilized to avoid escalated heat loss or heat gain, we see considerable savings in heating expenses. Use of setbacks as well as operational timings on the HVAC system ensures that it is used only when the house is occupied or when the thermostat threshold has been achieved. This further helps in the conservation of energy.

Figure 4.7 Monthly Electric Peak Load Profiles for Baseline Case



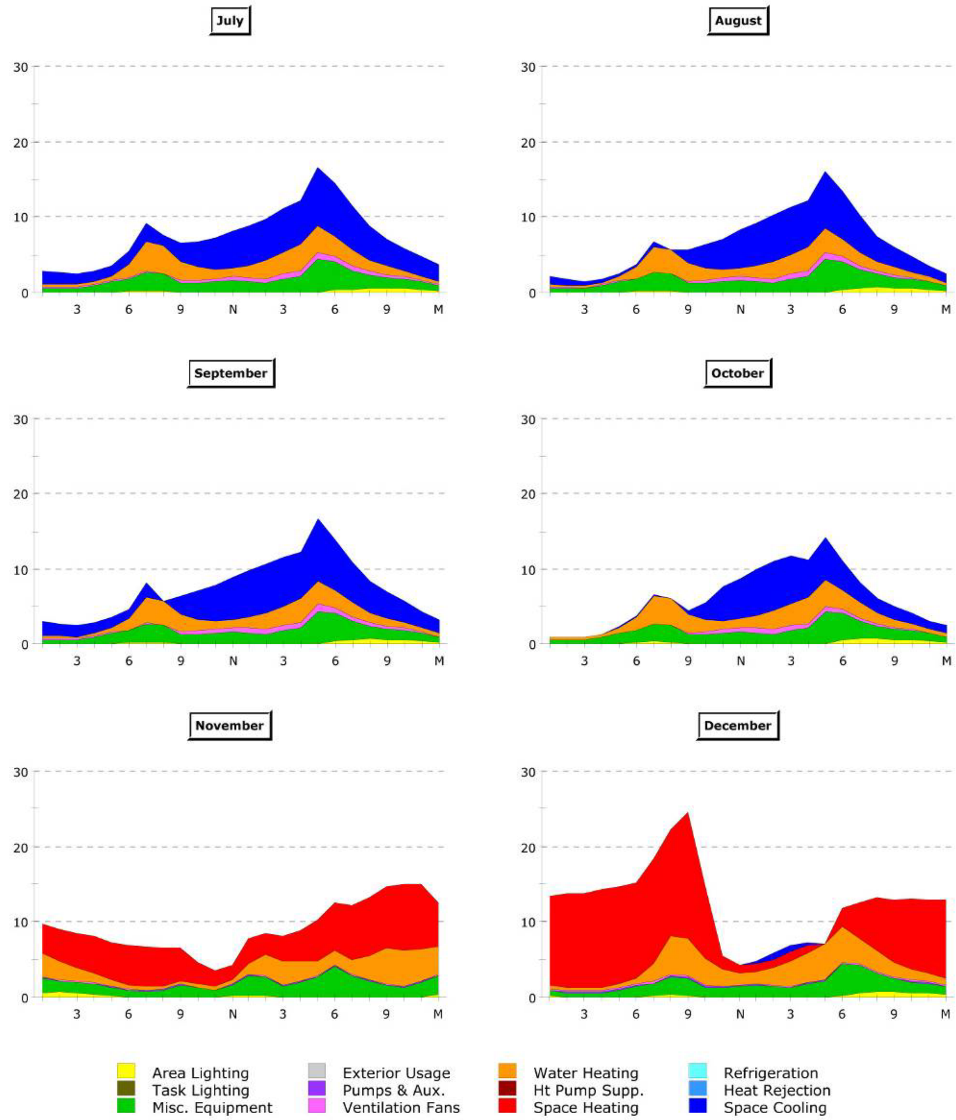
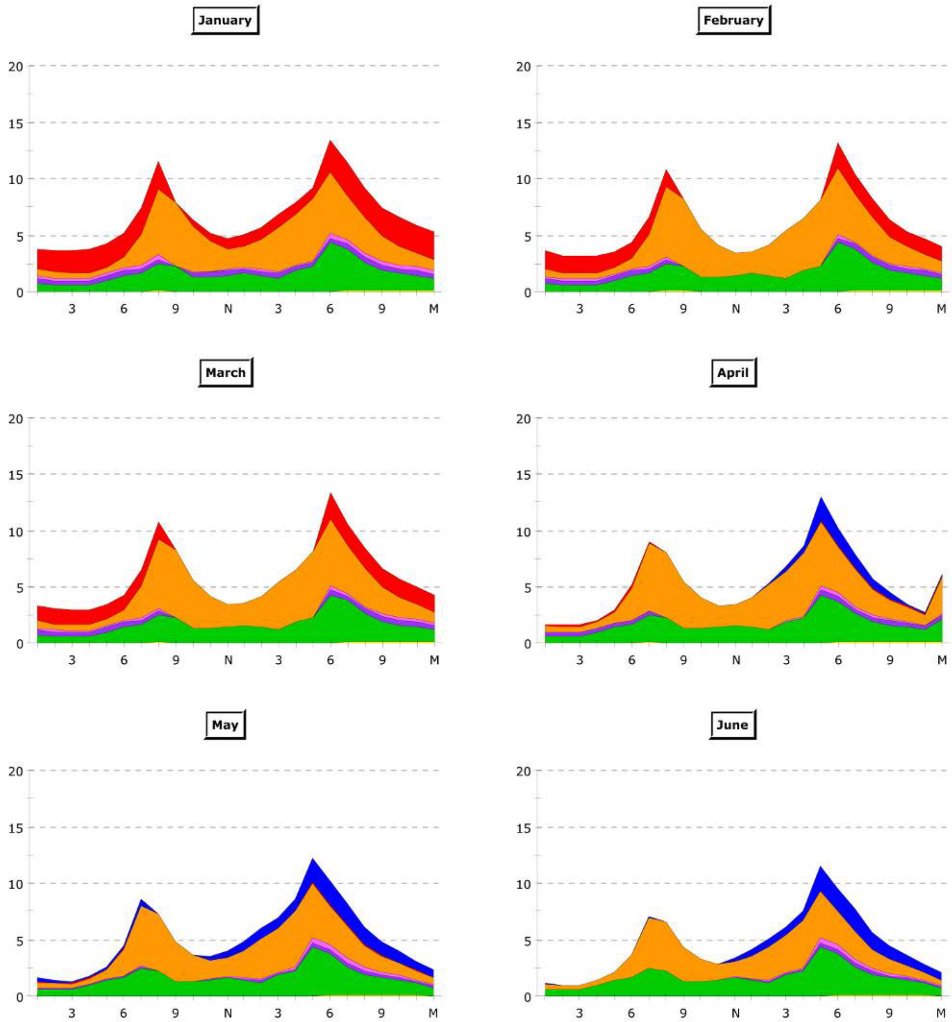
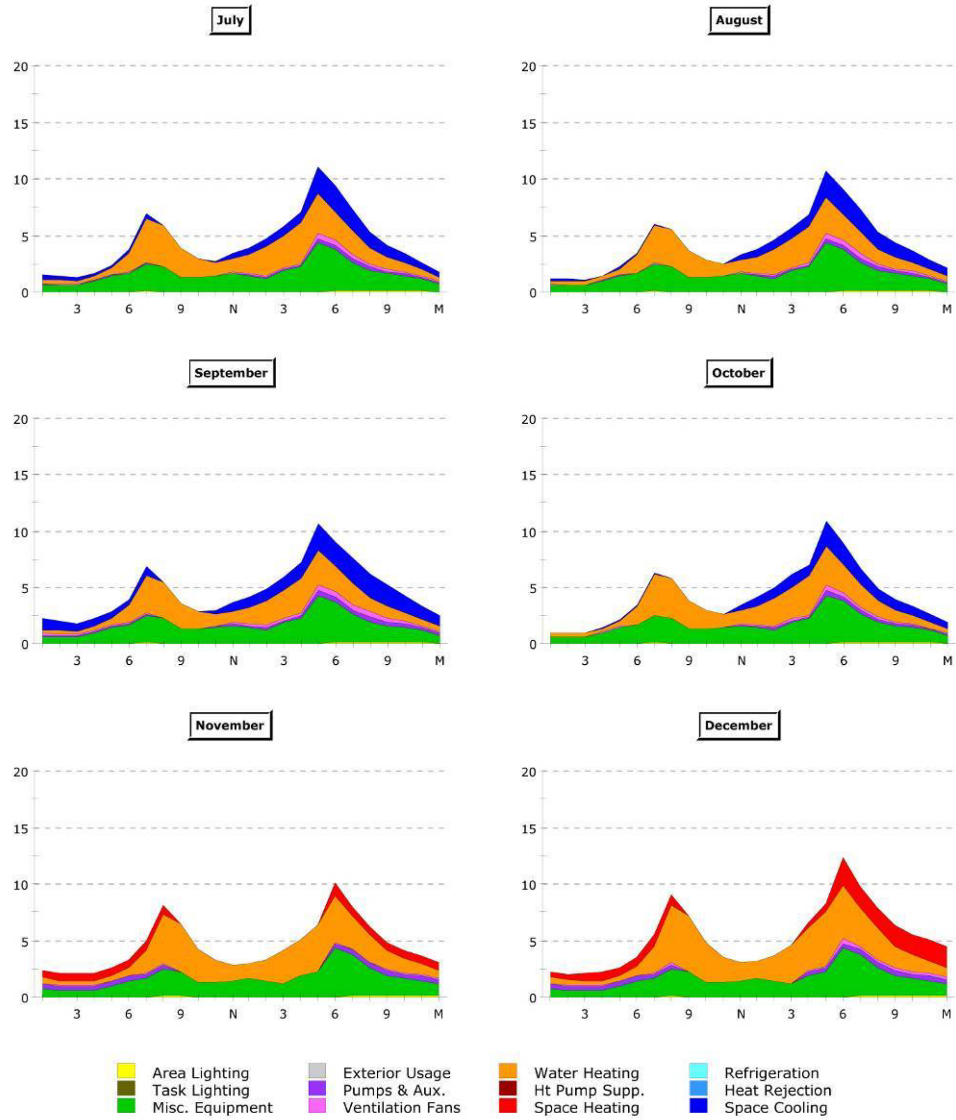

July
August
September
October
November
December
30
20
10
0
3
6
9
N
M
Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

Figure 4.8 Monthly Electric Peak Load Profiles for Low-Energy Case





It is evident from the graphs provided that the low-energy case uses 65% less energy than the baseline case. Much of this saving is attributed to the considerable reduction in the energy used for heating. Domestic water heating has also been simulated. However, it may be pointed out here that a continuous supply of hot water via a geothermal unit all year round would further decrease the energy consumption.

Table 4.9 shows the three low-energy cases generated during energy analysis. The first column shows the model using the passive solar design strategies, the low-energy model generated by E-10 software is shown in the second column and the last column represents the low-energy case developed by eQuest simulation. The R-values of the insulation have maintained except for the roof insulation in E-10, which is higher. The U-values of the windows also coincide. A sufficient amount of thermal mass has been provided as suggested by the passive solar calculations. The area of windows on all the facades is the same in all the three calculations. The total south glazing is equal to that used for the passive solar calculations. The total amount of energy saved in the Low-energy cases generated by both E-10 and eQuest is nearly 60%.

Table 4.9 Low-Energy models for the front house

Passive Solar House	E-10 Low-Energy case	eQuest Low-Energy case
SSF(No night time insulation)= 21(low) and 33(high)	**Walls**: 2X6 frame with sprayed polystyrene insulation. R=23.1	**Walls**: 2X6 frame with sprayed polystyrene insulation. R=23.1
Direct gain windows=445 sf.	**Roof**: Attic floor with blown polystyrene insulation. R=60.2	**Roof**: Attic floor with blown polystyrene insulation. R=49
Walls R-value= 23	**Floor:** Basement floor slab with carpet on rubber base. R=41.7	**Floor:** Basement floor slab (4") with carpet with fiber pad R=10
Windows U-value= 0.33	4x6 double glazed, low-e glazing on all windows. U=0.31	South,West and East Walls: Double low-e glazing. Air filled.North Glazing: Double clear glazing
Roof R-value= 49	6.8kW system	
Thermal Mass= 296 sf.	Fixed COP Heat Pump with setback	Ground Source Heat Pump with setback and an efficiency rating of 10.00
Total heat loss= 2.35 BTU/DD,sf	As recommended for 40° latitude	3' overhang on West, South and East windows
Total heat gain=6.878 BTU/hr,sf	Total Energy Savings 60%	Total Energy Savings 65%

Back House eQuest Simulation

Figures 68- 71 in Appendix C illustrate the eQuest simulation for the back house. It is clear from the results that a 50% savings in energy consumption is achieved in comparison to a baseline case. Parameters used for this simulation were identical to those used in the front house.

Summary

The results of both eQuest and Energy-10 complement each other. Both the simulations show that the low-energy case can achieve 50% and 65% savings in energy consumption in the back and front house respectively, thereby increasing the overall efficiency of the house. A considerable amount of energy may be conserved by properly and efficiently regulating the use of HVAC systems using thermostats. The use of a geothermal system further helps decrease total energy consumption.

Renewable Energy Systems

This part of the study focuses on renewable energy systems that may be utilized for purposes of heating/cooling and for powering houses. The two renewable systems have been investigated: i) a photovoltaic system for powering the house, and, ii) a geothermal system for heating and cooling the house. This section focuses on the description and operational factors of the renewable energy systems used in this design. Some calculative measures used to identify the size of such systems and the estimates for up-front investments required for these units are also been presented. A more detailed energy and return-on-investment analysis is presented in Chapter 5.

Photovoltaic System

Solar panels are used in the production of electricity from the sun. A solar cell is like an electric diode or a check valve that allows current to pass through it in the backward direction. Hence at night, in the absence of a charge controller or a diode to block the current flow, the solar cells will drain the charge from the battery charged during the day. Most solar cells are coated with silicon material; the electrons in the atoms of this material are energized by the photons in the sun's energy. The natural 'electrical diode effect' is thus overcome causing the current to flow in the 'forward' direction. An increased solar cell size increases the capacity of the current (Yago 1999, p.85).

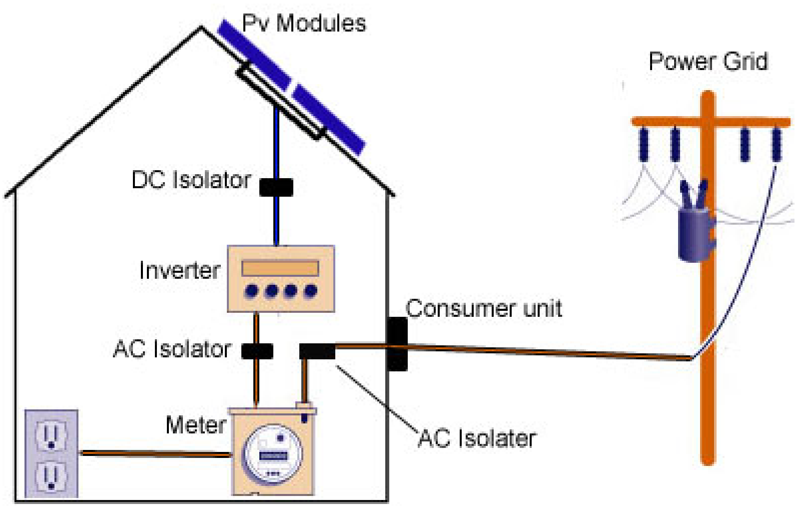
Solar energy does not harm the environment and the amount of pollution incurred in the production of the panels is minimal when compared to the pollution of the fossil fuels (Gevorkian 2006, p 34). Hence, solar energy has often been called clean energy. Given the rapid pace of advancement in solar technology, prices of these modules are expected to become more affordable in the near future (Gevorkian 2006, p 34).

Integration of this technology in the front and back houses for powering various household electrical gadgets as well as the geothermal heating and cooling system is discussed in this sub-section. The panels are applied at an angle of 40 degrees which is equal to the latitude of Manhattan, Kansas. This angle could be reduced by 15 degrees to maximize energy absorption in summer or increased by 15 degrees to optimize energy production in winter. For this project, a slope of 40 degrees is used, which results in no bias for seasonal benefits.

A grid connected system is proposed for this design since batteries pose fire hazards and the responsibility for maintaining them becomes cumbersome (consultation with a specialist in the field on 03.12.’08). They are also prohibitively expensive (http://www.scsolar.com/Batteries.html: 05/02/’08). When the sun’s radiation is available, photovoltaic panels produce electricity: otherwise the house draws electricity from the grid. Figure 4.9 illustrates how a grid connected system works where the grid is used as a backup system.

Figure 4.9 Electricity from a Grid connected PV System

(http://www.cel-f-solar.com/images/PV-GridSystem.jpg : 04/12/’08)



Building Integrated Photovoltaic System (BIPV)

There are different types of solar panels available such as framed solar panels, pv shingles, building integrated standing seam laminates, etc. Building integrated photovoltaic panels (BIPV) have been chosen for this project. One of the benefits of building integrated photovoltaic panels is that they do not stand out to take away the aesthetic beauty of the house. Instead, they blend in with the surrounding roofing materials while providing power at the same time. These panels can replace roofs, skylights and facades as shown in Figure 4.10. Hence the initial cost can be offset by saving on material and labor costs that would be spent in construction of the building components that the panels replace. Uni-Solar's PVL136 BIPV is used for this study; Figure 4.10 shows this product and Table 4.11 and 4.12 show the electrical and physical specifications of PVL 136 panels.

Figure 4.10 Application of PVL136T on a house

(http://www.scsolar.com/UniSolar.html: 01/20/'08)

BIPV application on the roof.

Figure 4.11 Physical Specification of PVL136T

(http://www.scsolar.com/UniSolar.html: 01/20/'08)

No. of Cells	Laminate Length	Laminate Width	Laminate Thickness	Weight (lb)	Minimum Slope	Maximum Slope
22	18'0"	15 1/2"	0.12"	17.8	1:12 (5°)	21:12 (60°)

Figure 4.12 Electrical Specification of PVL136T

(http://www.scsolar.com/UniSolar.html: 01/20/'08)

Performance	Per Cell	PVL 136-T
Rate Power (Watts)	6.2	136
Nominal Operating Voltage	--	24
Operating Voltage (Volts)	1.5	33
Operating Current (Amps)	4.13	4.13
Open-Circuit Voltage (Volts) 25° V	2.1	46.2
Open-Circuit Voltage (Volts) -10° C &1250W/m2	2.39	52.7
Short-Circuit Current (Amps)	5.1	5.1
Short-Circuit Current (Amps) at 75°C &1250 W/m2	6.7	6.7
Fuse and Blocking Diode Rating (Amps)	8	8

Calculation and Sizing of the number of BIPV modules

The sizing of the PV panels was done using the Energy-10 simulation software. In this section, an effort is made to calculate the energy demands of the household electrical equipment - the results of the simulation agree closely with those from the calculations as shown in Table C.9 in Appendix C. It was noted that using solar power for equipment that has high energy consumption such as water heater, clothes drier, electric stove or a complete home heating system would be prohibitively expensive. It is, therefore, recommended that natural gas be used to power such equipment.

Table 4.13 shows the calculation of the total amount of energy required to power various equipment in the front house. A calculation for the number of modules of PVL136T required is shown by Table 4.14.

Figure 4.13 Electrical Demand Calculation: Peak Load

MAIN HOUSE			
Description	**Watts X**	**Hrs/Wk =**	**Wh/Wk**
Refrigerator (frost free 16 cu. Ft)	725	168	121,800
Microwave	750	3.5	2,625
Laptop	50	21	1,050
Television (19")	75	21	1,575
Fans Ceiling (3)	195	18	3,510
Ventilation fan	13	2	26
Washer	500	0.3	150
Cell Phone Charger (4)	15	15	225
Vacuum Cleaner	1000	1	1,000
others	200	3	600
Lighting Appliances	217	25	5,425
	Total WH/Wk		**137,986**
BASEMENT APARTMENT			
Description	**Watts X**	**Hrs/Wk =**	**Wh/Wk**
Refrigerator (frost free 16 cu. Ft)	725	168	121,800
Microwave	750	3	2,250
Laptop	50	21	1,050
Television (19")	75	21	1,575
Fans Ceiling (2)	130	18	2,340
Ventilation fan	13	1	13
Washer	500	0.3	250
Cell Phone Charger (3)	10	15	150
Vacuum Cleaner	1000	0.5	500
others	200	3	600
Lighting Appliances	102	25	2,550
	Total WH/Wk		**133,078**
Total WH/Wk of Front House (House + Basement)			**271,064**

Figure 4.14 Calculation of the number of PVL136T Modules Required

	Front House	
1	**Unisolar PVL 136-T**	
2	Energy Use (WH/Wk)	271,064
3	Energy Use (WH/day)	38,723
4	Average Sun hours/day for Manhattan KS	6
5	Total KW/Hr required ((Ans 4/Ans 5)/1000)	6.4
6	**Total Energy**	**6.4 KW**
7	Energy from the panel	136 Watts
8	**No. Of panels** (Ans6/Ans7)	**47**
11	**Area (18'X15.5"X47)**	**1092sf**

Calculation of BIPV for back house has been provided in Tables C.10-C.11 in Appendix C. The calculations may be summarized as follows:

Front House:

Total number of panels = 47

Cost of panels= 47 X \$699 = \$32,853

Total area of south facing roof required for the panels = 1,092 sf

Back House:

Total number of panels = 47

Cost of panels= 47 X \$699 = \$32,853

Total area of south facing roof required for the panels = 1,092 sf

Total area of south facing roof required for the panels (front & back house) = 2,184 sf

Total area of south facing roof available = front house +back house roof + carport roof

= 900+ 990 + 500

Total south facing roof area available = 2390 sf

Hence, it was concluded that there is enough south facing, unobstructed roof area available for the solar panels to generate adequate electricity for both the houses.

E-10 simulation also sized the PV which was 6.8 kW for the front house as seen in Table C.9 in Appendix C 9. The size for the back house is 6.8 kW. The calculations above are based on the electricity consumed by various electrical equipments. A 6.4Kw system was arrived at after the calculations above which are close to E-10 simulation results. Forty seven modules of BIPV will be required both in the front and back house to generate 6.8kW of energy each.

Maintenance of Solar Panels

Due to solid state technology, lamination techniques and total lack of moving parts in the solar panels, there are zero maintenance requirements. However the panels do need to be rinsed bi-yearly with a water hose to clean them from dust accumulation that may otherwise adversely affect their output. (Gevorkian 2006, p. 37)

Drawbacks of Solar Panels

Besides being quite expensive, solar panels are very complex to use. Solar panels can generate electricity only during the day when it is sunny hence they cannot provide energy on demand (Gevorkian 2006, p. 35).

Inverters

Inverters are used to convert the DC power generated by the solar panels into AC power used by most of the electrical equipment. Since the house is also connected to the grid using equipment running on direct current is not an option. Moreover, wiring for DC equipment is very expensive and bulky and needs to undergo regular replacement.

The sizing of the inverters was calculated using the Xantrex technology sizing calculator. Table 4.10 gives the specifications of the inverter and Table 4.11 provides the string configuration as well as the number of modules required for both the front and back house. (www.xantrex.com/support/gtsizing/index.asp?lang=eng#calculator : 03/12/'08)

Table 4.10 Inverter Specification

Inverter:Xantrex GT3.3N (240)	
Pnom	3300 Wac
Idc max	17.5 Adc
Vmptmax	550 Vdc
Voc	600 Vdc
Vmptmin	200 Vdc
Efficiency	95.5 % Avg Efficiency
Temperature Specifications	
Recorded Low Temperature (°F)	**Recorded High Temperature (°F)**
-15	95

Table 4.11 Inverter String Configuration

String Configuration		
10 Modules 4 Strings	STC	5440
	PTC	5200
	CEC	4966
	Max Voc at Min Temp (Vdc)	**Min Vmp at Max Temp (Vdc)**
10 Modules	514.29	283.96

The total cost for a set of inverters is $2,245 and the cost of two inverters, one for the back house and the other for the front house is $ 4,490 (http: //www.altersystems.com /catalog/gridtie-inverters-xantrex-gt-inverters-c-1_5_117.html?sort=3d&page=1: 03/21/'08).

Geothermal System

A geothermal heat pump (or ground source heat pump) technology is a very efficient means for providing the heating and cooling needs of both residential and commercial spaces and today such systems are being widely used. This subsection briefly discusses the working principle of this system, the type of system being used and its proposed location on the site. The sizes of the system were derived from the simulation by eQuest and the costs involved were obtained from various websites.

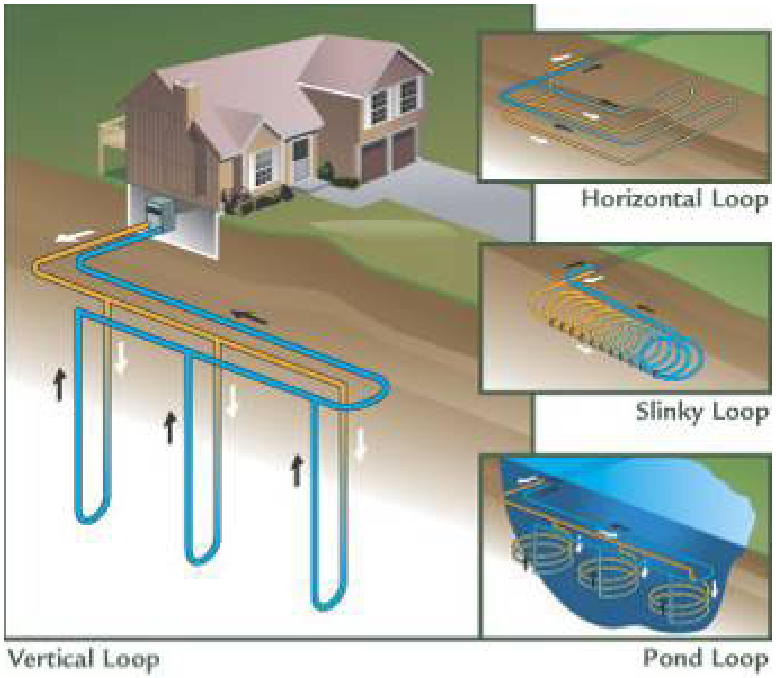
Working of a geothermal system

This system works by using the naturally existing heat in the earth for heating and cooling, instead of relying on fossil fuels. The temperature below the surface of the earth remains constant all year round (between 50°F and 60°F) (http://www1.eere.energy.gov /geothermal/overview.html#heat_pump: 05/04/'08). A ground source heat pump taps into this heat source during winter to heat the house while the reverse mechanism takes place during the summer – heat is transferred from the house into the ground. Thus, the ground acts very much like a *'heat source'* during winter and *'heat sink'* during summer (www1.eere.energy.gov/geothermal: 03/20/'08)

The system proposed for the project uses a water based liquid medium to exchange this heat using ¾" polyethylene pipes which are buried into the ground. This heat exchange fluid absorbs heat from the earth and transfers it to the geothermal unit in the house. Here, the heat is extracted from the fluid and delivered to the various spaces. In summer this process is reversed to deliver dehumidified, cool air to the house.

There are three primary types of piping systems: 1) ground loops, which involve horizontal loops; 2) vertical loops and; 3) pond loops. When there is enough area on the site for laying out the pipes a horizontal loop is used. If there is a scarcity of land, a vertical piping system is preferred. A pond loop is used when there is a pond of sufficient size and stable water levels available nearby. Since, the amount of land is restricted for the case under study, a vertical loop system was chosen. This looping system requires 150-200 feet deep trenches and 300-400 feet of pipes per ton. The back yard of the house shall be utilized for this purpose. Figure 4.15 shows the different types of piping systems available.

Figure 4.15 Types of Ground Loops: Vertical Loop chosen for this project
(http://www.geoecs.com/geothermal_how_it_works.html: 04/01/'08)



The basics of the various types of equipment required for compressing and pumping heat to and from the earth in summer and winter respectively are shown in Figure 4.16. One of the major advantages of geothermal systems is that it makes available a constant supply of hot water both during the summer and winter seasons without the use of a conventional hot water heater or solar hot water heater. On an average, this system uses one unit of electrical energy for moving three units of energy from the ground (http:// www.eere.energy.gov/consumer/your_home/space_heating_cooling /index.cfm /mytopic= 12660: 03/20/'08). During fall and spring when is the pump is usually not in operation, 'full demand' systems that use a separate heat exchanger are also available to meet all of the hot water requirements of the household. (www1.eere.energy.gov/geothermal: 03/20/'08)

Figure 4.16 Different parts of a geothermal system and their functioning

(http://www.geoecs.com/geothermal_how_it_works.html: 04/01/'08)

Cooling Season

1. Geothermal system
2. Warm air returns from your home
3. Cool air delivered to your home
4. Earth loop circulating pump
5. Warm water going to the earth loop
6. Cool water returning from the cool earth
7. Normal water heater
8. Free hot water from geothermal system

Heating Season

1. Geothermal system
2. Cool air returning from your home
3. Heated air delivered to your home
4. Earth loop circulating pump
5. Cool water going to the Earth loop
6. Warm water returning from the Earth loop
7. Normal water heater
8. Free hot water from geothermal system

Maintenance

The geothermal system requires lower maintenance than conventional systems and most of the underground systems are worry free and come with a 20 to 50 year warranty. The components that remain accessible above the ground typically last for 20 years or more and easily lend themselves to maintenance. Moreover, they do not take up a large area and hence can easily be accommodated in the utility spaces provided in the dwelling designs in this thesis (http://www1.eere.energy.gov/geothermal/pdfs/26161b.pdf : 04/03/'08).

Cost of the System

On average a geothermal system costs $2,500 per ton of capacity. According to simulations run in eQuest, the front house requires a 5 ton capacity while each of the back houses required 2 ton capacity. The cost of the geothermal system for the front house is $12,500 and for each back house is $5,000. Thus the total cost of the geothermal system for both the front and back houses was calculated to be about $22,000 (http://www1.eere. energy. gov/geothermal/pdfs/26161b.pdf: 04/03/'08).

Advantages of Geothermal Heat Pumps

(Source- http://www.envirotechgeothermal.com/geothermal_advantages.html: 05/04/'08)

Some of the advantages of geothermal heat pumps are:

- They have lower operating costs than a conventional system.
- They have lower maintenance requirements in comparison to a conventional system and they last more than 20 years if the periodic checks and filter changes are done properly.
- There are no dangers of carbon monoxide pollution.
- One system provides both cooling and heating.
- Free hot water can be obtained in both summer and winter by a simple connection. In summer the extra heat removed from the house during the cooling process is deposited in the water tank instead of the ground to supply one with free hot water.
- Geothermal heat pumps maintain comfortable interiors without the hot and cold air blasts characteristic of conventional systems. This system also dehumidifies the air during the hot season.
- This system is quiet in operation as it uses principles similar to a refrigerator or freezer.
- An environmentally friendly water based solution is used as the heat exchanger.

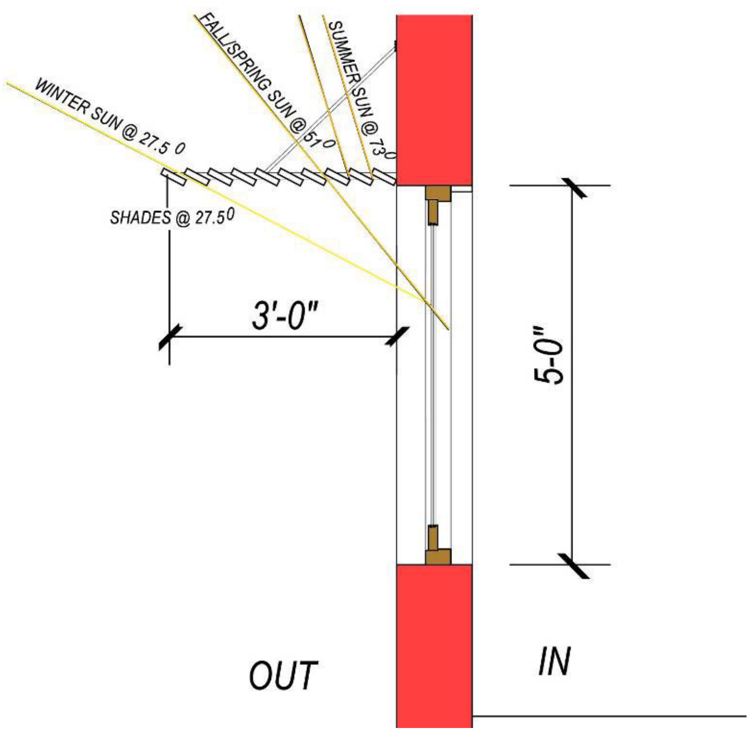
Shading Device and Architectural Drawings

The dimensions for a shading device, for the south façade, were calculated in order to enable it to block unnecessary summer sun and thereby decrease heat gain. The north windows do not have shades since they were deemed unnecessary. Although simulations did show that shading devices reduced the amount of heat gain, it was ranked near the bottom of the list of energy efficient measures in terms of effectiveness (Figure 2).

The book *Sun, Wind and Light* by G.Z Brown and Mark DeKay (2001) and the workbook, *Bioclimatic Dwelling Design* by Gary J. Coates (2007) was used as a source for calculating the depth of the horizontal shading device on the south facades. Figure 4.17 shows the calculated horizontal shade with a depth of 3' which blocked the summer sun and allowed the fall, winter and spring sun. The same shading device was also used in the west and east windows. This information was also used in the eQuest simulation to achieve the final results.

Figure 4.17 Horizontal Shading Device

(Brown 2001, p. 264, 265, 266)



After completing the simulations and passive solar analysis the original architectural plan for the Type 1a house had to be updated. In the front house glazing for east façade was reduced by 70 sf and west facade was reduced by 30 sf. Similarly glazing on the north façade was decreased by 50 sf and the glazing; on the south wall was decreased by 60 sf.

The back house also had to be updated in terms of its glazing, on the east and west façade the glazing was decreased by 50 sf and on the south façade the glazing area was reduced by 30 sf.

The following figures show the changes that were incorporated to achieve the final zero energy design for the Type 1a house. These changes were not incorporated in the design documentation shown in Chapter 3. Figure 4.18 shows the place for the geothermal ground loop as well as the building integrated photovoltaic panels on the roof of the houses and the carport.

Figure 4.19 shows the placement of thermal masses in the floors of the front and back house. Figure 4.20 shows a section of the front and back house displaying the overall changes and some of the materials used. Figures 4.21 – 4.23 show the changes in the elevation in terms of decreased glazing area the four facades. The south and west roof profiles have changed to accommodate the solar panels in case of the front house. The north façade has minimal changes from the original design and is hence not included.

Figure 4.18 Site for the Renewable Energy Systems

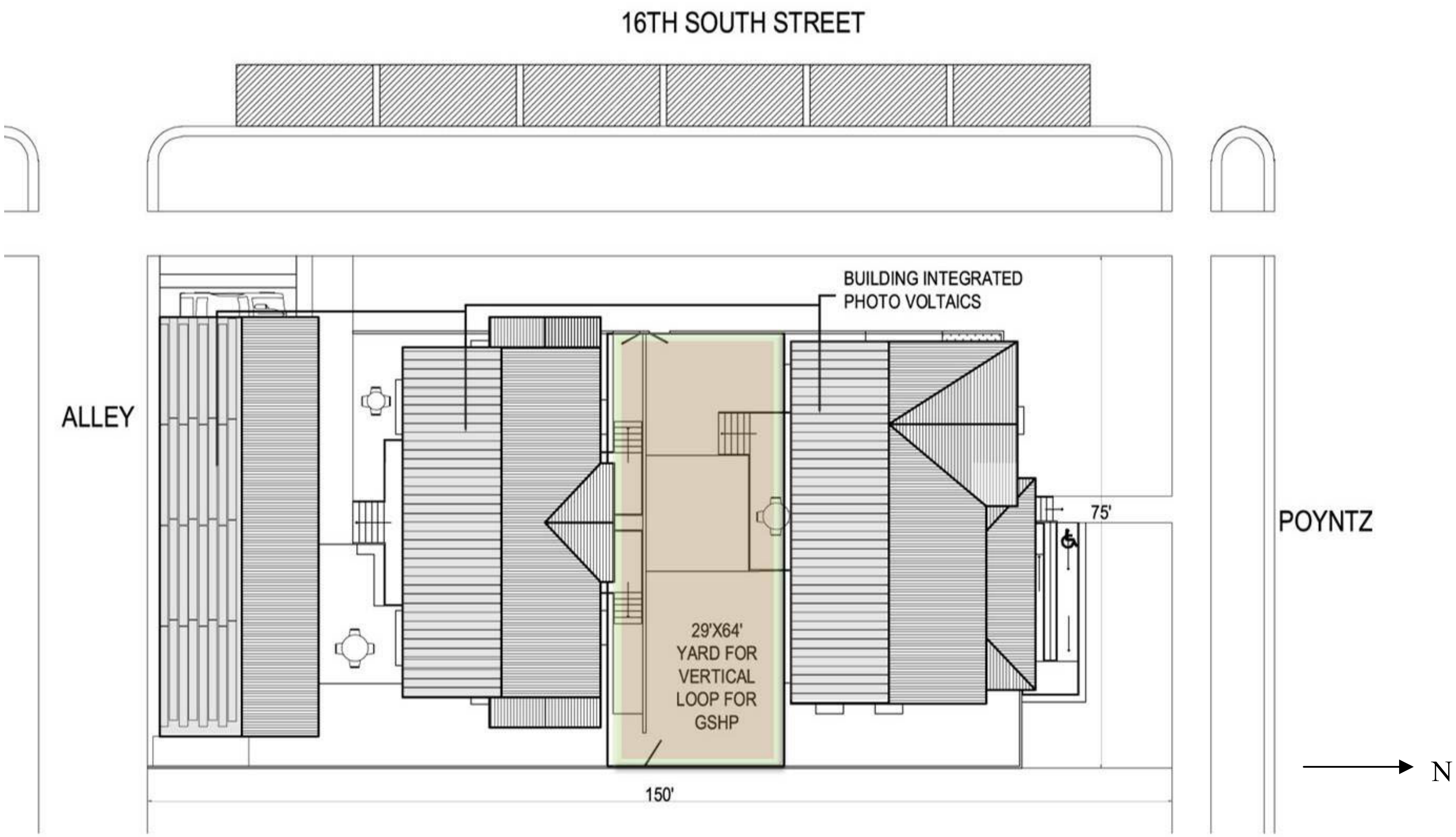


Figure 4.19 First Floor Plan showing the area for thermal mass

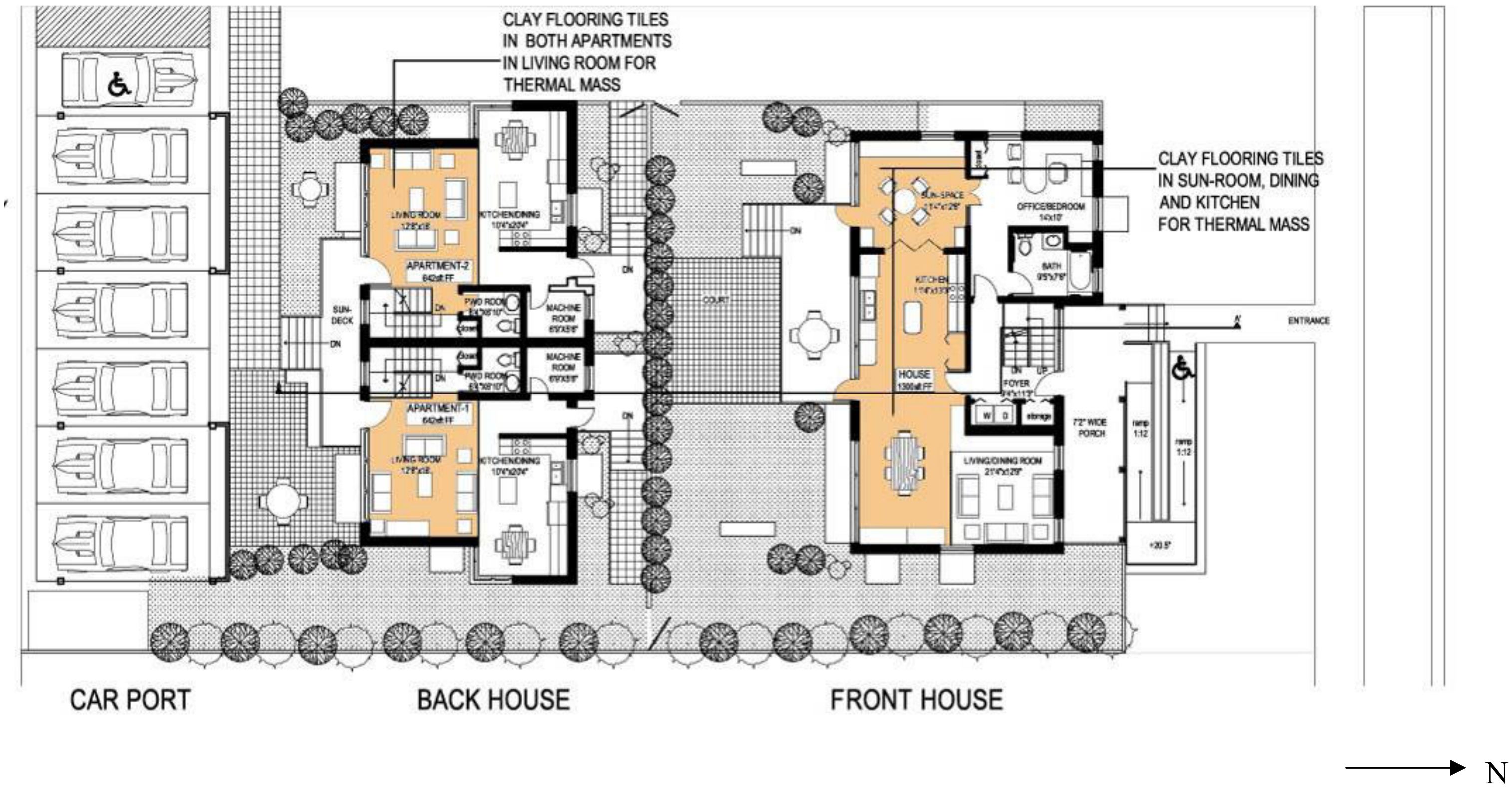


Figure 4.20 Section AA'

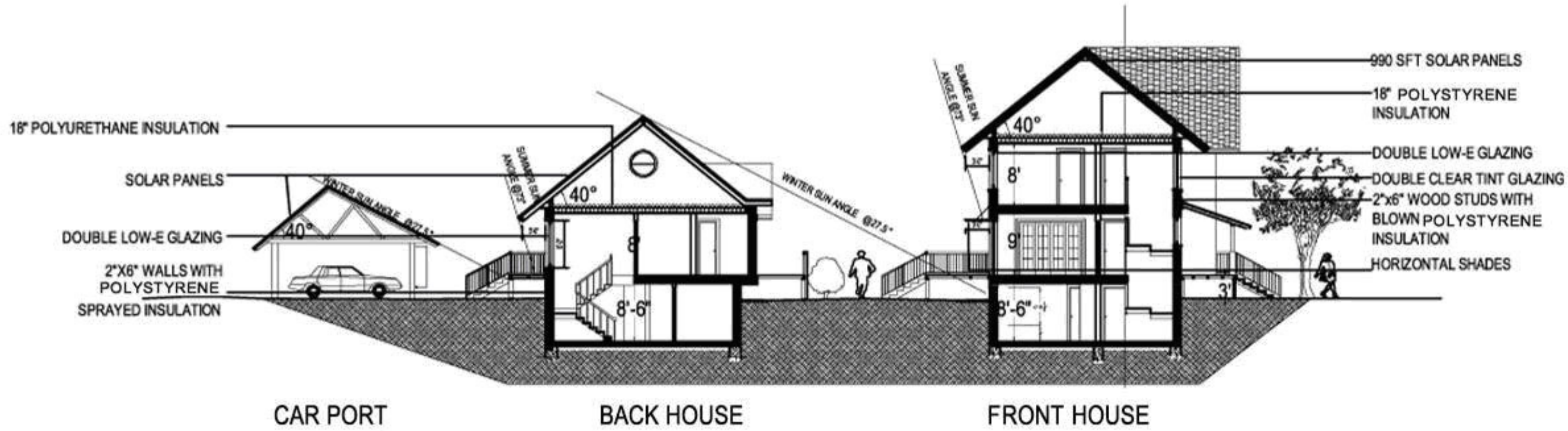


Figure 4.21 South Elevation

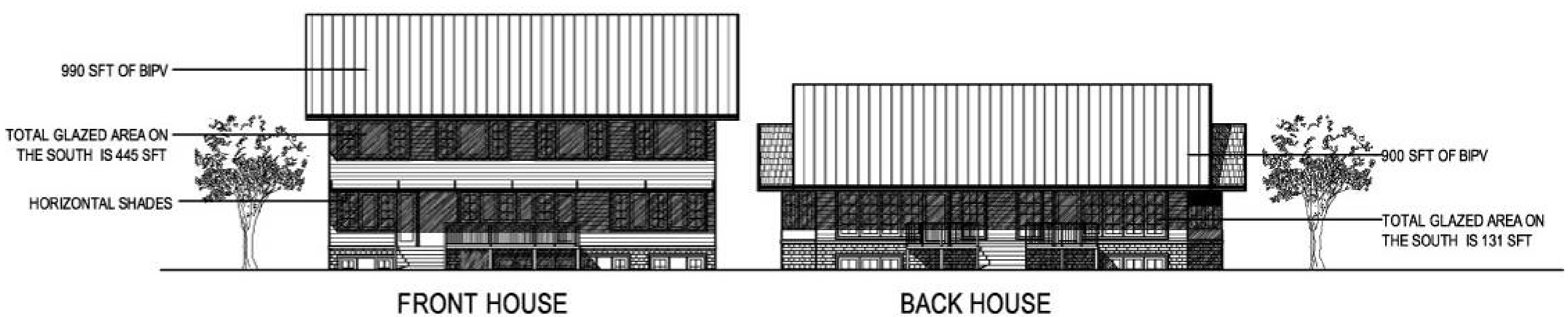


Figure 4.22 East Elevation

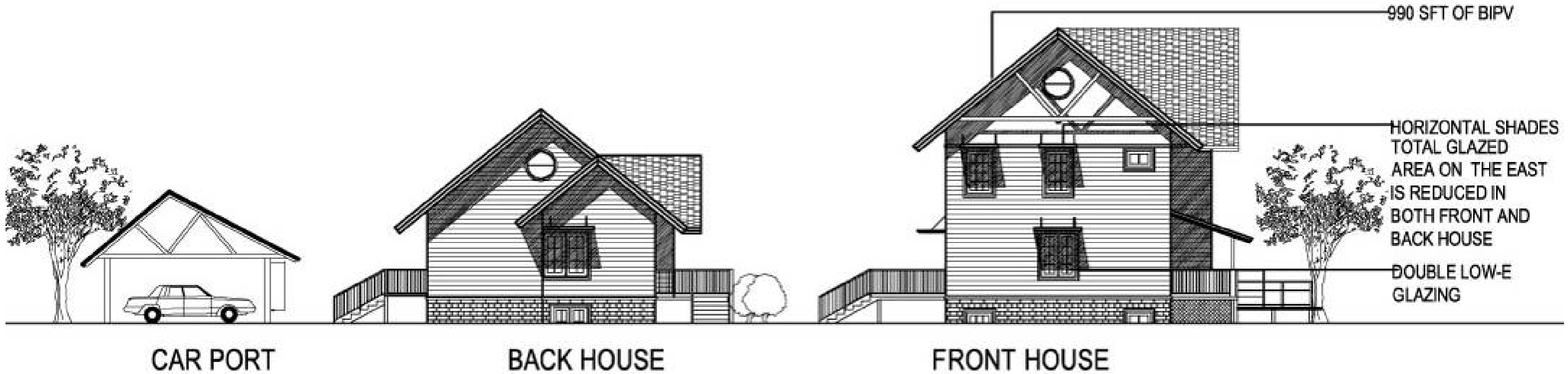
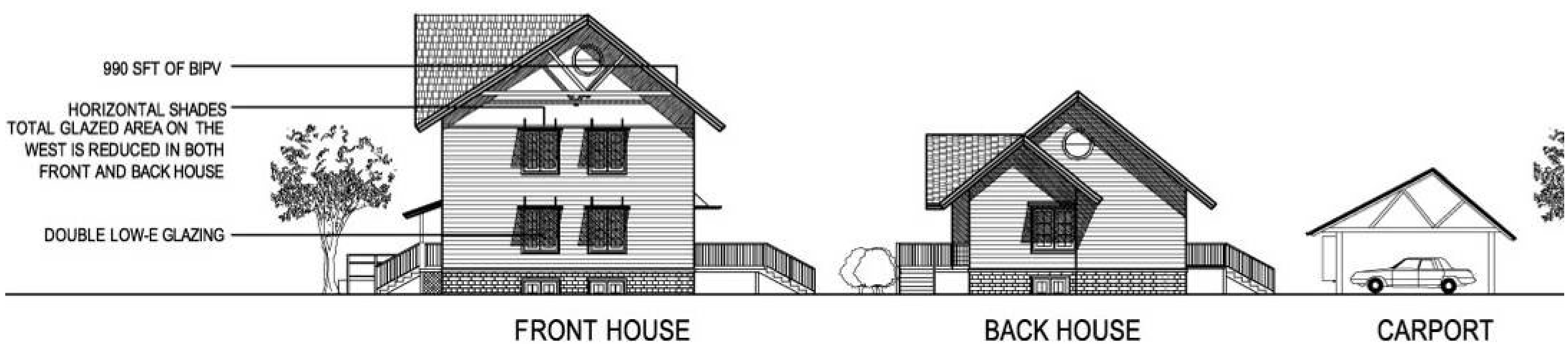


Figure 4.23 West Elevation



At the end of the study it was possible to achieve a ‘zero energy’ design with reduced energy needs of 60-65% for the front house and 50% for the back house and the use of a grid connected solar system and a geothermal HVAC system. Passive heating and cooling design was also utilized to achieve appropriate amount of heat gain from the sun in the colder season. Many of the thumb rule calculations do comply with the results of the simulations, with some exceptions like the results of thermal mass calculation.

CHAPTER 5 - Economic Analysis

This Chapter summarizes the results of an economic viability study conducted for the proposed infill house. The subject of study is yet again the Type 1a house which was used to conduct an energy analysis. Type 1a house proposes a front house with a home office occupied by owner, back house and basement as rental units. This option has a sun deck towards the south in the front and back house units.

This Chapter is divided into three sections:

i) **Section One** – This section deals with the economic viability of the proposed design. Comprehensive calculations of construction costs, mortgage payments and profits from rent along with maintenance costs have been considered in determining the economic benefits of building such units.

ii) **Section Two** – This section deals with a succinct study on energy economics with regards to the energy efficient strategies presented in Chapter four. A comprehensive set of calculations are included to demonstrate the financial benefits of the proposed renewable energy systems over conventional energy systems.

iii) **Section Three** - This section discusses **Federal Tax Credits** awarded for energy efficient building products and renewable energy systems that are proposed to decrease the consumption of energy by the house.

Section One

An important goal of this thesis was to determine the economic viability of the proposed front and back house options. A typical 'Type 1a' house is taken up as the subject of this study. The cost of the building envelope was derived by using *'RS Means Square Foot Costs'* (2008) and the template used for economic analysis presented in '*Affordable Housing'* (2001) edited by Gary J. Coates has been extensively used for arriving at the economic viability of the design proposal. The following pages summarize the calculations and are subsequently followed by conclusions.

Cost of Building Envelope

It is necessary to know the square foot cost of the building envelope in order to calculate the economic viability of the design. In the absence of local technical support for forecasting the building cost, *RS Means Square Foot Costs* (2008) was employed. There are four types of houses described for cost estimating purposes: economy, average, custom and luxury class. The cost of the 'average class' was chosen for this analysis using the standard methodology described in the book. The cost was based on a standard 2X4 construction with a combination of wood siding and brick veneer. *RS Means Square Foot Costs* (2008) states that *"Prices listed are costs that include overhead and profit of the installing contractor. Total model costs include an additional markup for general contactors, overhead and profits and fees specific to class of contractors."* (Balboni 2008, p.4) The final cost estimate thus took into consideration the labor cost, contractor's profit and a contingency percentage. Since the site development cost and architect/engineer's fees were not a part of the costs, they were later added as percentages of the final cost. These percentages were also provided by *RS Means Square Foot Costs* (2008).

Square foot costs of both the front and back house were calculated. Tables 5.1 and 5.2 show the cost of an 'average class' house. The costs are based on a standard house with one full bath, kitchen, half bath, asphalt roofing and gyp board interior finish. Costs for additional bathrooms, kitchens and various other modifications have also been taken into account. The percentages of brick veneer and wood siding used for the exterior were also calculated in order to arrive at the average cost of the wall assembly. The location factor serves to adjust the cost based on the location of construction. The location factor for Topeka, KS, was used due to unavailability of the same for Manhattan, KS. It should be noted, therefore, that the cost for construction for Manhattan could possibly vary slightly. The common wall factor for the back house apartments was also considered at arriving at the cost for the same.

Table 5.1 Cost of Front House

(RS Means 2008, p.16, 17, 30)

Main Building				Cost per S.F Living Area		
Cost per Square Foot of Living Area, from pg. 30				$		81
Basement Addition		100% Finished		$ +		15.55
Main Building: Adjusted cost per S.F of Living Area				**$**		**96.55**
MAIN BUILDING TOTAL COST	**$97/SF**	**X**	**2,600**	=		**$252,200**
Modifications and additions for basement apartment						
Additional Baths						
Upper Floors 1 Full @ $5,129 1 Half @ 3,107				=		$ 8,236
B'ment Floor 2 Full @ $5129				=		$10,258
Additional B'ment Kitchen				=		$5,771
ADJUSTED TOTAL BUILDING COST				=		**$276,465**
Cost for excavation, spread and strip footings and Underground piping				**X**		**2.40%**
Cost				**=**	**$**	**283,100.16**
Location Factor (Topeka, Kansas)				**X**		**0.79**
Location Replacement Cost				**=**	**$**	**223649.2**
Architect/Designer Fees				**X**		**10.00%**
FINAL BUILDING COST					**$**	**$246,014**

Table 5.2 Cost of Back House

(RS Means 2008, p.16, 17, 28)

Main Building				Cost per S.F Living Area	
Cost per Square Foot of Living Area, from pg.28				$	121.95
100% finished basement				$ +	30.75
Main Building: Adjusted cost per S.F of Living Area				**$**	**152.7**
MAIN BUILDING TOTAL COST	**$152.7/SF**	**X**	**656**	=	**$ 100171.2**
Cost for excavation, spread and strip footings and Underground piping				**X**	**2.40%**
Cost				**=**	**$ 102575.30**
Town House (Common wall Factor)				**X**	**0.95**
Cost				**=**	**$ 97,446.5**
Location Factor (Topeka, Kansas)				**X**	**0.79**
Location Replacement Cost				**=**	**$76,983**
Architect/Designer Fees				**X**	**10.00%**
FINAL BUILDING COST					**$84,681**
FINAL BUILDING COST FOR TWO APARTMENTS				**X 2**	**$169,363**

The final cost of the front house was computed to be $246,014 and that for the back house was $169,363.

Economic Viability Analysis

In order to carry out a realistic analysis of the economic viability of the proposal in Type 1a that proposes a front house with a home office occupied by owner, back house and basement as rental units, a detailed calculation of the mortgage payments, taxes and maintenance costs had to be computed. The costs of construction tabulated in Tables 5.1 and 5.2 were used to carry out the economic viability analysis using the template given in *Affordable Housing* (2001). In order to make this template valid for the current year, prevailing market rates for mortgages in Manhattan, Kansas, were utilized.

Owing to a difference in interest rates for commercial and residential units, it was necessary to perform two analyses - one for the front house and the other for the backhouse. In general, interest rates for units meant for rental or commercial use are higher than those available for residences.

Appendix D shows detailed calculations based on the template. There are two sets of analyses presented depending on the percentage of mortgage payments. Analysis A describes the calculation when the mortgage for the front house is 80% of the total cost while Analysis B shows the same for a case when the mortgage for the front house is 90% of the total cost. Since the backhouse is intended to be a rental unit, the mortgage was considered to be 80% of the total cost and could not be increased any further. Additionally, the interest rates for 30 years on the loan amount were assumed to be 6.5% and 7.5% for the front house and rental back house units respectively. Finally, the minimum monthly operating cost for the houses was calculated. The minimum annual income to be invested to own the houses was thereby deduced.

Analysis A in appendix D shows that considering net rental profits of $393/month from the back house duplex rentals and $1,350/month from the three bedroom basement apartment in the front house, total monthly cost for the infill house amounts to $129/month. The annual investment needed to own both the front and back houses is therefore $6,200. Analysis B shows that the total monthly cost for the infill house is $302/month and the annual investment to be made to own the house is $14,500. The summary of the results are documented in Tables 5.3 and 5.4. Both the scenarios presented in analyses A and B suggests that given the size of property the annual investments are definitely a bargain. A monthly cost in the range of $129 to $302 to live in and ultimately own a 3,600 square foot front house and 2,400 square foot back house rental units would be a worthwhile option indeed, especially given that this cost is lower than that of an average single bedroom rental home in Manhattan, KS.

Table 5.3 Economic Viability Analysis A

80% Mortgage for Front and Back House:	
Land Cost	$39,380
Total cost of Front House construction	$285,394
30 year loan Principle Interest 6.5% (PI)	$1,451
(PI + Tax+ Insurance)/Month	$1,872
Rental profit (front + back house) refer analysis A Appendix D	1350+393= **$1,743**
Adjusted monthly cost for housing	**$1,872-$1,743= $129**
Annual income to be Invested in housing to own	($129/0.25)X12= **$6,129**

Table 5.4 Economic Viability Analysis B

90% Mortgage for Front and 80% mortgage for Back House:	
Property Cost	$39,380
Total cost of Front House construction	$285,394
30 year loan Principle Interest 6.5% (PI)	$1,623
(PI + Tax+ Insurance)/Month	$2,045
Rental profit (front + back house) refer analysis A Appendix D	1350+393= **$1,743**
Adjusted monthly cost for housing	**$2,045-$1,743= $302**
Annual income to be Invested in housing to own	($302/0.25)X12= **$14,500**

It will also be observed in the analysis that the backhouses cost less than the front house since the cost of land is included in the front house calculation. So, without any additional land cost a home owner can build an accessory apartment on the same property. It will be seen in the calculations that after paying for the back house mortgage and maintenance, the remainder of the rental income can be used toward paying the mortgage of the front house.

The 2000 census states that the average household income for Manhattan is $48,289 and by 2005 this income was projected to be $61,520. The infill house, therefore, seems like a viable option for an average family in Manhattan. Furthermore, both the backhouse and the basement rental units are good sources of income and provide adequate help to the owner of the front house in paying for the mortgage, taxes and insurance.

During a regular site visit, it was learned that the mortgage for a 1,900 sf, 100 year old house, situated close to the proposed site, is $900 / month. This information further boosts the economic viability of the proposed design which is a new construction with above average interior finishes. Although the down payments are slightly on the higher side, the savings and income generated after occupancy does lend an affordable appeal to the scheme.

After discussion with local appraisers and an architect, it became clear that the proposal presented in this thesis represents a viable solution to the present day housing needs in the city of Manhattan. Furthermore, such units would also bring increased revenue to the city because of the taxes levied for such densely developed properties. Therefore, the infill housing option can be seen to benefit both the homeowner as well as the city economically while offering a new kind of housing for the city. Hence, it is concluded that the front and back house design scheme is an economically viable option for the housing needs of the city.

Return on Investments

A common method used by local property investors to find out whether or not a property is worth buying or developing is determining its return on investment (from Tables 5.1-5.2). Typically, a percentage value ranging from 6 to 8.7 is considered necessary.

In the case of this analysis, we know that the total investment to be made for buying land and constructing front and back house is $ 415,377. From the calculations presented in Appendix D, it is seen that annual gross rent is $37,800. This gross rent generates a 9% return on investments. The annual taxes and insurance is $8,059 for the front and back house. Hence, the net rental income is $29,741. Thus, the final return on investment is 7.1%, which is a favorable percentage. Had this return on investment been lower, it could possibly have been concluded that the property was overpriced.

This method of calculation was acquired from a real estate professional practicing in Manhattan, Kansas and it shows that the front and back house design would be a financially sound investment.

Section Two

Section Two of this Chapter looks into the economic viability of the proposed renewable energy systems for the front and back house design. The cost of building a more energy efficient building envelope using results from the software Energy-10 has been derived. A set of calculations has been used to demonstrate the return on the investment and the financial benefits of proposed renewable systems compared to systems those relying solely on fossil fuels. The fact that tax credits are awarded to owners of structures employing energy efficient components and renewable energy systems has also been taken into consideration.

Cost of Building Envelope

Results of simulations run on Energy-10 show that by incorporating energy efficient measures in the house, the overall energy efficiency of the building could be increased by up to 60% for the front house and 50% for the back house. *RS Means Square Foot Costs* (2008), *RS Means Assembly Cost Data* (2008) and *RS Means- Green building: project planning & cost estimating (2002)* was used to arrive at a realistic cost following the standard methodology described therein. Tables D.12 - D.15 in Appendix D show the cost of front and back house using a 2X6 wood frame construction with blown polystyrene insulation, efficient windows and a highly insulated roof. Drawings for the upgraded energy efficient house are included in Chapter 4.

Tables D.12 - D.15 show that the cost of the front house is $265,892 and that of the back house is $163,717. Comparing these costs to that of an average house using 2 X 4 wood frame construction, as shown in Table 5.1 and 5.2, it may be inferred that cost of the front house increases by $19,878 and that of the back house decreases by $5,646 by using a 2X6 construction. Total increase in the cost for building a more energy efficient house is, therefore, $14,232. This is indeed a good bargain in view of the increased savings in the utility bills. Decrease in the cost of the back house may be attributed to a reduction in the cost of interior finishes without compromising on the energy efficient materials described before. On the other hand, the cost of the front house is increased due to added emphasis on materials providing higher insulation of the building envelope.

Figures 5.1, 5.2, 5.3, 5.4 present the expected lifecycle cost for the front and back houses in comparison to a reference case as derived by Energy-10.

Figure 5.1 Lifecycle cost for Front House: Reference Case

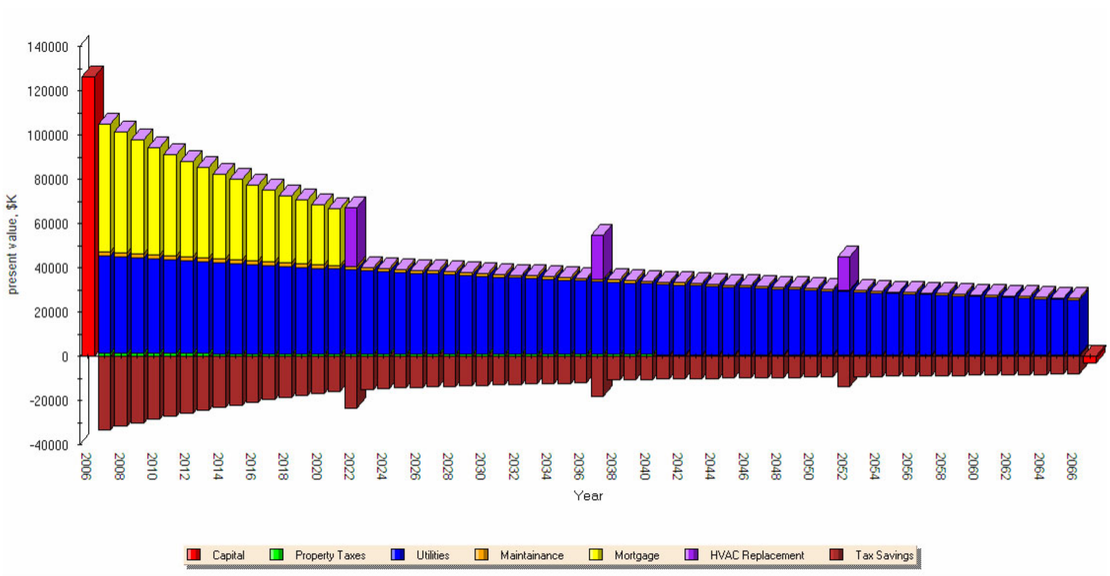


Figure 5.2 Lifecycle cost for Front House: Low-Energy Case

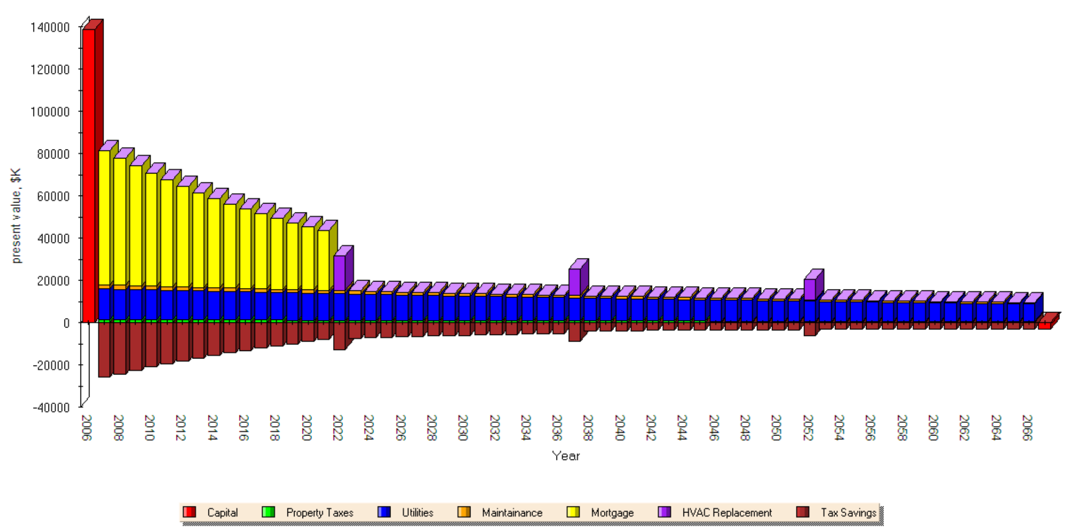


Figure 5.3 Lifecycle cost for Back House: Reference Case

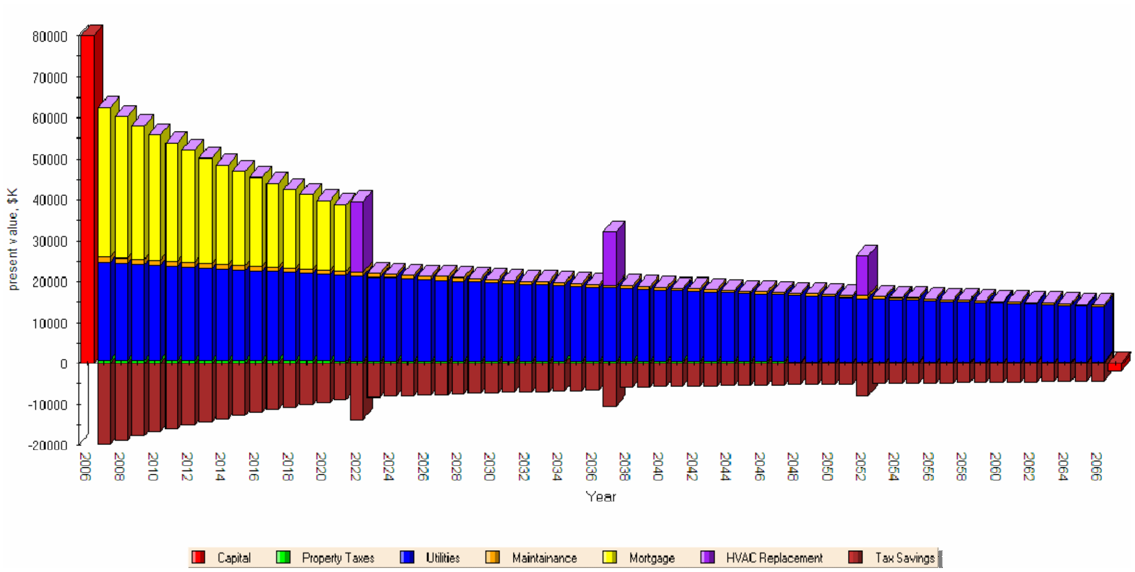
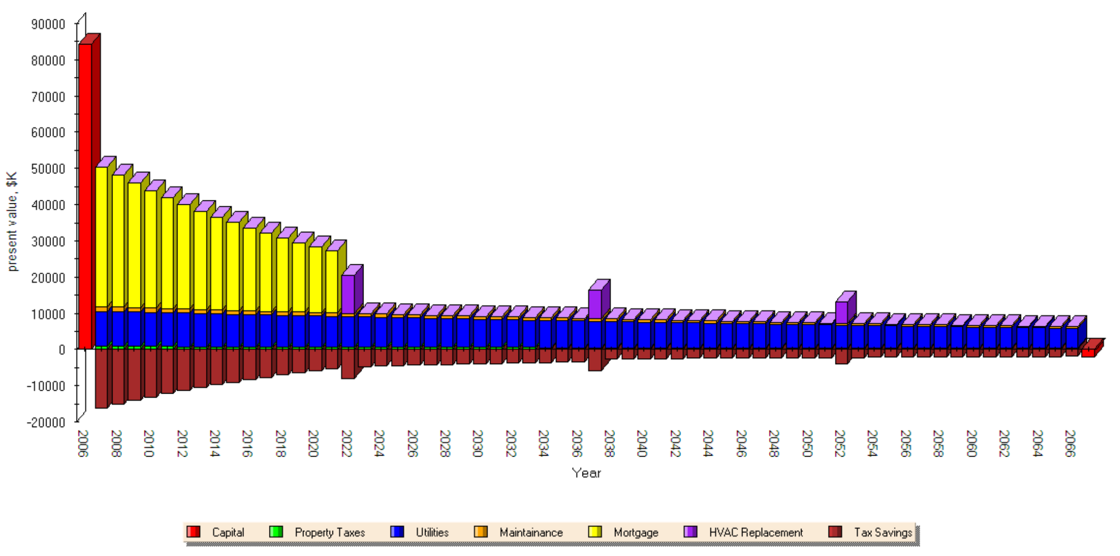


Figure 5.4 Lifecycle cost for Back House: Low-Energy Case



It is evident from the figures above that the overall lifecycle cost of the low-energy case using the energy efficient strategies is less than that of a reference case.

Economic Viability of Photovoltaic Panels

Apart from investigating the economic benefits of building a more efficient building envelope, some time and effort was also devoted towards studying the economic viability of the renewable energy systems proposed to be incorporated into the designs for the front and back house. The aim of this sub-section is to calculate the lifecycle cost of the photovoltaic solar panels and examine whether or not the investment made for this system could be retrieved within its average estimated lifespan of 20 years,.

The lifecycle cost of a photovoltaic system can be calculated by using the formula:

$LCC = C + M_{pw} + E_{pw} + R_{pw} - S_{pw}$ (where the subscript *pw* indicates the present worth of each factor) (http://photovoltaics.sandia.gov/docs/LCcost.htm: 4/05/'08)

Thus to find out the lifecycle cost it was necessary to determine:

1. C= Capital cost of the equipment which is considered as a single sum paid at the initial year of the project.
2. M= Maintenance cost for all the years of operation.
3. E= Sum of yearly fuel costs.
4. R= Anticipated replacement costs for all equipment within the lifespan of the PV system
5. S=Salvage Value of the PV system, which is its net worth in the final year of its lifecycle. Usually the final salvage value is assumed to be 20% of the initial investment cost.

For life cycle analysis it is necessary to determine discounted future costs because of the time value of money. The rationale behind this principle is simple - one dollar received today is worth more than the promise of $1 next year, because the $1 today can be invested and can earn interest. Hence to determine the lifecycle cost, it was necessary to find out the future discounted cost (http://photovoltaics.sandia.gov/docs/LCcost.htm: 4/05/'08).

The capital cost of the PV system is the cost of panels and inverter and includes an estimated transportation cost of $700 (determined after consultation with the manufacturers on 6th April 2008). The PV system does not require any fuel for its operation hence the value for E is 0. However, the proposed system does use an inverter which needs to be replaced every 10 years. Hence, R is the cost of the inverter. The fact that it has to be replaced in the 10th year of operation suggests that the present value of the inverter has to be multiplied by the Single Present Worth Factor which is used to discount a cost expected to occur in a specific year in the future. Assuming a net discounted rate of 5% in 10 years single present worth factor becomes 0.614. (http://photovoltaics.sandia.gov/docs/LCcost.htm: 4/05/'08)

Lifecycle cost of the PV system for the front house, therefore, becomes:

LCC= C + M pw + E pw + R pw - S pw

For the calculation of the lifecycle cost the various values are:

C= 32,853+ 2,245 +700 = $35,798 (Cost of PV system is described in Chapter 4)

M_{pw} =0

E_{pw}=0

R_{pw}= 2245 /0.614= $3,656

Lifecycle cost of the PV system for the front house

S_{pw}= 20% X 35798 = $7,160

The lifecycle cost of the PV in the front house is = C + M_{pw} + E_{pw} + R_{pw} - S_{pw}

=35798 + 0 + 0 + 3656 -7160

The lifecycle cost of 6.4 kW PV in the front house = $ 32,294

The cost of the PV in the back house is same as that for the front houses. Therefore, lifecycle cost of 6.4kW PV in the Back House = $ 32,294

The total lifecycle cost of the front and back house (12.8kW) PV= $64,588 (rounded to the nearest hundred dollars)

For the PV panels to be economically viable, this lifecycle cost should be retrieved by the panels within 20 years of its operation. Savings made was calculated by comparing savings in electricity/energy bills over the 20 years during which the PV system was estimated to be functional. While calculating the energy cost for 20 years, the present cost was multiplied by a Uniform Present Worth factor in order to discount annually recurring costs (for example, the annual fuel cost of a generator). Assuming a net discounted rate of 7% on the investments and an inflation of 4% in the energy costs (http://www.guardian.co.uk/business/2008/jun/13/inflation.usa: 9/01/'08), the discount rate of 3% was used for calculating the present worth of future energy costs. Hence, for a period of 20 years the Uniform Present Worth factor that has to be multiplied by the present cost of electricity considering a discounted rate of 3% is 14.877 (http:// photo voltaics.sandia.gov/docs/LCcost.htm: 4/05/'08).

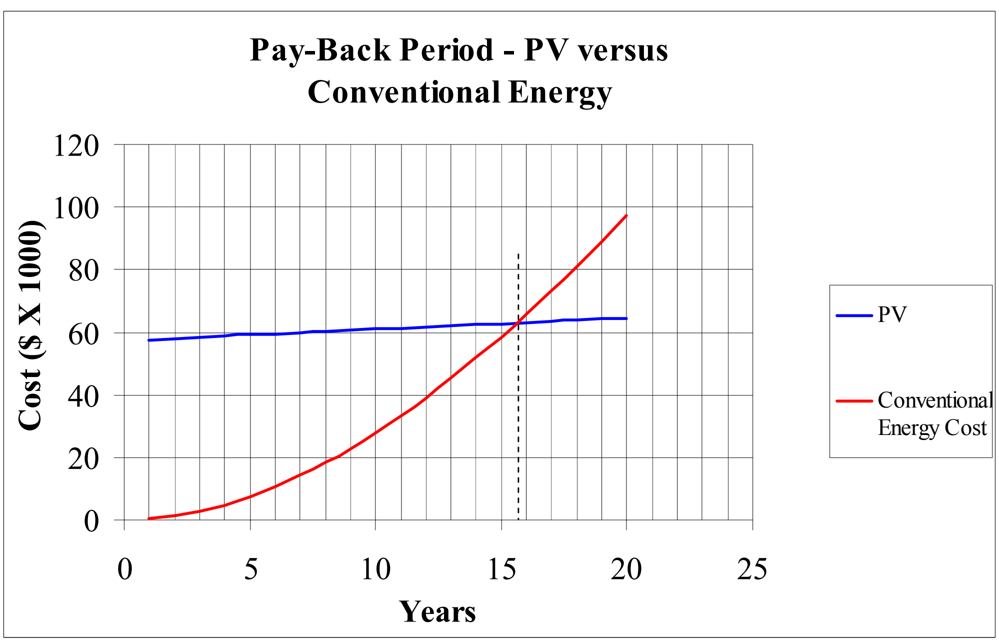
Savings in Energy Costs for 20 years = Cost of energy/kW X time period X amount of energy used X uniform present worth factor

= 0.07 (http://www.westarenergy.com: 4/05/'08) X (20 X 365) X 12.8 X 14.877

Savings in Energy Costs in 20 years = $ 97,307

Figure 5.6 and Table D.16 in Appendix D, shows the payback period of the proposed PV system. The initial cost for the 12.8kW PV system is assumed to be $57,277 (after deducting the scrap value) and the cost of the inverter to be replaced in the 10th year of operation is used as the operating cost for this calculation. The investment in the grid system is $0 as the meter and the electrical wiring is used in the proposed grid-connected PV system. The operating cost for grid-connected conventional system is $328/year, which is the utility cost of the 12.8kW energy being generated by the PV system. Hence, the pay-back period in this case is 15.6 years. Although this pay-back may seem high, for housings addressing aging-in-place, this would be a viable option, wherein the utility would be free of cost after the 16th year of residency for the rest of the lifetime of the owners.

Figure 5.5 Pay-Back Period of Proposed Photovoltaic System



Hence, from the above calculations, it can be stated that the investment made towards installing the 12.8kW PV panels in the front and back house will be retrieved within the lifespan of the PV panels. Each day the home owner will be saving about 12.8kW worth of electricity cost and given the increasing prices of electricity the investment on the PV panels can be considered as a good option.

Economic Viability of Geothermal Heat Pump System

The geothermal heat pump was another renewable energy source proposed to be used for heating and cooling the house. A succinct exercise was undertaken to investigate the financial benefits of incorporating such a system in the design. The results are reported below.

Geothermal systems incur lower maintenance costs than conventional systems - most of the underground systems are worry free and come with a 20 to 50 years warranty. The components that remain accessible above the ground typically last for 20 years or more and easily lend themselves to maintenance (http://www1.eere.energy.gov/geothermal/pdfs/26161b.pdf : 04/03/'08). The major task was to find out how much savings could be accumulated over a period of 20 years of the geothermal system's operation in comparison to a conventional HVAC system.

The investment needed to add a geothermal system is $2,500 per ton of capacity. (http://www1.eere.energy.gov/geothermal/pdfs/26161b.pdf : accessed on 04:03:'08) According to simulations run (Chapter 4), the front house requires a 5 ton capacity while each of the back houses requires a 2 ton capacity. Thus the total cost of the systems for both the front and back houses was calculated to be about $22,500. A conventional system costs about $1400 per ton of capacity with air conditioning. So the total cost of a conventional system with a capacity of 9 tons for both front and back house is $12,600.

Geothermal systems typically deliver up to five times more energy than they consume when compared to other types of heating and cooling systems, thus creating savings on energy bills every month. A cost break down generated by Energy-10, Figure 5.5 and 5.6, shows that when using a Ground Source Heat Pump (GSHP), one may expect about 90% savings in the heating costs for both the front and back house in addition to 70% savings in cooling cost for the front house and 85% for the back house in comparison to a conventional electrical HVAC system.

Figure 5.6 Annual Cost Breakdown- Front House

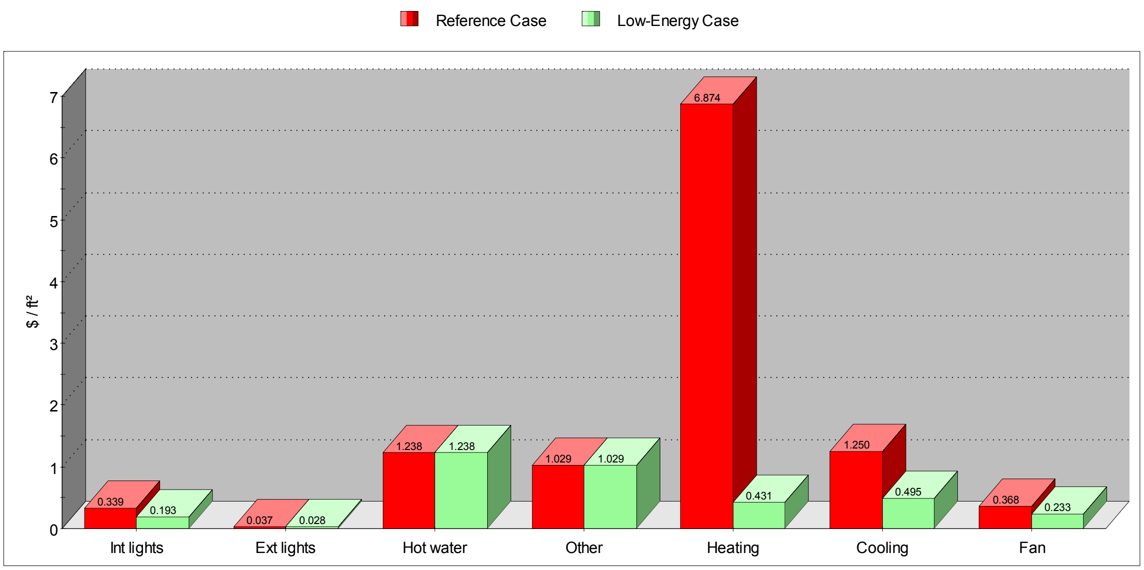


Figure 5.7 Annual Cost Breakdown- Back House

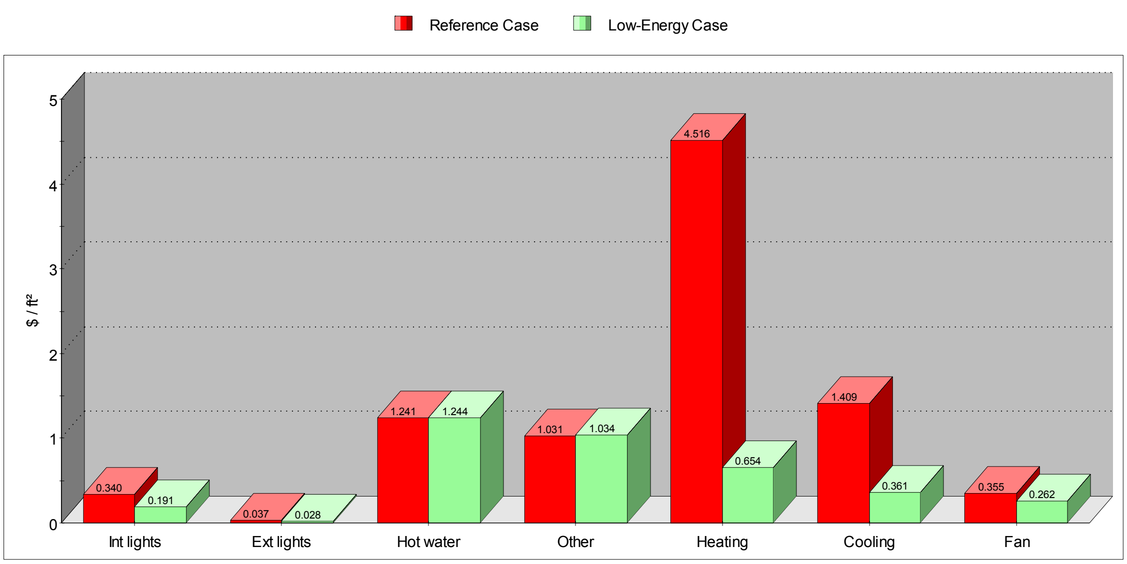


Table 5.5 shows a comparative Table for heating and cooling between Conventional and GSHP for a typical house in the Kansas City Area.

Table 5.5 Operational Heating and Cooling Costs

(http://www.geoecs.com/geothermal_economics.html: 04/05/'08)

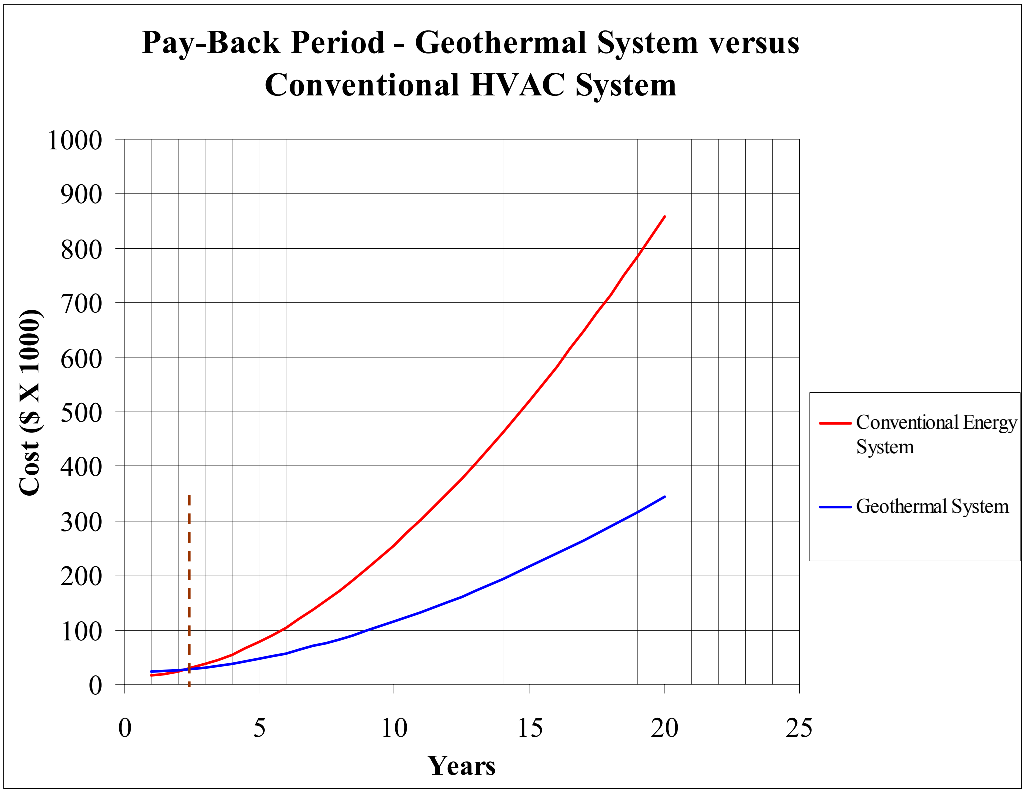
System description	Efficency %	Heating cost	Cooling cost	Hot water cost	Constant fan	Total operating cost (heating cooling and hot water)	HVAC monthly
Geothermal (Envision Series dual capacity)	388%	$176	$128	$216	$25	$541	$45
8SEER/Single Stage/PSC-R22	80%	$671	$411	$327	$111	$1420	$118

Hence the HVAC savings per month are $73/typical house when a ground source heat pump, is used which is a reduction of 62% /month on the utility bills. Hence the savings/month for two such homes (considering front and back houses to be two separate houses), the total savings/month is $146. Assuming the uniform present worth factor considering a discounted rate of 3% to be 14.877 (for a period of 20 years), the total savings in 20 years = 146 X 12 X 20 X 14.877 = $ 521,290 (http://photovoltaics.sandia .gov/docs/LCcost.htm: 4/05/'08).

As savings of $521,290 easily surpasses the initial investment of $22,500. However, this investment does not include the maintenance costs. The above approximate estimate of the ground source heat pump shows that this renewable system is a very economically viable option even though the initial investment is somewhat high.

Figure 5.8 and Table D.17 in Appendix D, shows the payback period of the Geothermal System proposed for the front and back house in comparison to a conventional HVAC system as shown in Table 5.5. The initial investment for the 9 ton Geothermal System $22,500 and its operating cost (heating, cooling and hot water) is $1082/year. The initial investment for a 9 ton conventional system is $12,600 and its operation cost is $ $2,840/year.The payback or the break even point for the front and back house is 2.5 years, showing that an investment in this system will prove to be a sound one. Hence, it can be said that Geothermal System is both an economic and an energy efficient system.

Figure 5.8 Pay-Back Period of Proposed Geothermal System



Financing options are, however, easily available from agencies like ECS Geothermal, at Kansas City, that offers a zero down payment, 6 months 0% interest financing.

Section Three

This subsection describes the tax credits that may be available by using energy efficient building components as well as renewable energy systems. To qualify for the tax credits the reduction in the total consumption of energy should be 50% or more. In the energy analysis presented in Chapter 4, it was concluded that the total energy saved would amount to 60-65% for the front house and 50% for the back house, thereby making the tax credits applicable to the proposed design. Table 5.6 shows the tax credits that may be obtained and suggests that it can indeed result in a significant amount of savings through reductions income tax. Unlike a deduction, which reduces the amount of income subject to tax, a tax credit directly reduces the tax itself. (http: //www.energystar.gov /index.cfm?c=products.pr_tax_credits#s1: 04/05/'08)

Table 5.6 Tax Credits for Front House

(http://www.energystar.gov/index.cfm?c=products.pr_tax_credits#s1: 04/05/'08)

Product	Specification	Tax Credit
Windows	Energy Star or meets IECC requirements	10% of cost, upto $200 for all windows, skylights and storm windows
Doors	Meets IECC requirements	10% of cost, upto $500
Storm Door in combination with a wood door	Meets IECC requirements	10% of the cost, upto $500
Insulation	Meets IECC requirements and amendments	10% of the cost, upto $500
Geothermal heat pump	Energy Star or meets IECC requirements	$300
Photovoltaic System	Must provide electricity in the house and comply to the fire and electrical codes	30% of cost, upto $2,000
Additional Tax Credits		
Homes achieving 30% savings from heating and cooling	Improved building envelope contributing 1/3 of the energy savings in compliance with the IECC codes	$1,000
Homes achieving 50% savings from heating and cooling	Improved building envelope contributing 1/5 of the energy savings	$2,000
Total Tax Credit		**$7,000**

Since the design proposes use of the same technology for both the front and back houses, a tax credit of $7,000 each may be obtained. Hence the total tax credit for both the front and the back house is $14,000. This additional income further supports the economic viability of the energy efficient front and back house design.

Energy Efficient Mortgages are also available today for homes with lower operating costs. Such mortgages are available from either the government-insured loan programs or from conventional money lenders. Energy efficient homes pay for themselves, however, the initial investment may be higher on such homes, and this is where the energy efficient mortgages can help. With such mortgages one can invest in upgrading and existing house to a more energy efficient model, buying an already energy efficient house or build an energy efficient house that is affordable. Homeowners with energy efficient houses can spend more on their housing expenses given their savings in the utility costs. Such homes need a certified energy evaluation to qualify for the mortgage. Energy efficiency can be used as an attractive selling point if one decides to put the house on the market. (http://www.infinitepower.org/ home-eem.htm: 09/22/'08)

In conclusion, although the initial investments for energy efficient house design might be on the higher side, this should not deter people from opting for them since this investment can pay off handsomely during the lifetime of the house. Along similar lines, calculations presented herein also show that although renewable energy systems require moderately higher initial investment, considerable savings may be expected through reduction in utility bills during subsequent years of operation.

CHAPTER 6 - Conclusion

'*A conclusion is the place where you got tired thinking.'* Martin Henry Fischer

This thesis focused primarily on addressing two critical issues confronting contemporary architects namely, changes in the present day American Lifestyle Diversity and family composition and The Global Environmental Issues of peak oil and global warming. A front and a back house design option incorporating energy efficiency boosting mechanisms was presented as a viable architectural solution that was demonstrated to adequately address both of the above issues.

The proposed designs not only pose as flexible house but also answered some of the housing issues of Manhattan, Kansas as outlined by *Housing Manhattan: Planning for the Future*. The proposed designs have an owner occupied as well as rental units in the same lot. The proposed design could be built on existing empty lots in the city or could replace degraded buildings in the R-3 zoning districts.

The Manhattan Comprehensive Urban Area Plan: April 2003 envisioned building cohesive neighborhoods with a variety of housing types – the proposed front and back house option caters to this need of the city (http://www.ci.manhattan.ks.us: 3/13/'08). It could not only provide additional spaces and income for the family owning the front house, but could also potentially increase the densities of existing neighborhoods. Thus, apart from being an academic exercise, the thesis also presents a feasible remedy to real-life issues confronting Manhattan today.

Apart from catering to a typical American family household with two parents and children, these types of houses also fulfill the demands for variations to the standard family configuration. Multigenerational home, home with an office are some of the housing types that cater to the demand of families with such needs. It was also possible to achieve a solution for aging in place, in which case, the back house played a crucial role. The three house types designed for this thesis could be easily converted from one to the other within the realm of the matrix presented, without changing the outer envelope, thereby demonstrating the flexibility of spaces to accommodate different lifestyles.

In all the scenarios, backhouses have been designed as rental units for people looking for an affordable space in the heart of the city of Manhattan. However, they could easily be used according to the owners' needs. Hence, with different types of families or groups of people living in the proposed infill housing, this project explored the options for increasing the density as well as diversity of residential neighborhoods. In the process, walkability and diversity, two principles of The New Urbanism, are also achieved through the front house back house design (http://www.newurbanism.org/newurbanism/principles.html: 05/05/'08).

Most of the lots in Manhattan are oriented in the elongated North-South direction; the lot chosen for this thesis also had the same orientation. The design was guided by bioclimatic design principles and building codes so the designed options could be built with little or no alteration on similar sites. Elevations of the front and back house were treated so that they shared the features of the neighboring homes. Such front and back houses could help in meeting the housing needs while also promoting diversity and density without distorting the architectural character of existing residential neighborhoods.

All the units have been designed after reviewing the building and accessibility codes. If the city were to modify its current zoning to allow for such units then these designs could readily be built without any further compliance issues. Any one type of the proposed front house could be built as a stand alone unit. The front house could still function as a flexible house to meet needs of occupants with the basement apartment helping to generate additional rental income. With changes in zoning the proposed back house could be built behind any existing house in the older neighborhoods of Manhattan to serve the needs of the owner. Hence, the proposed front and back houses could be built together or as separate units altogether.

Although sun-decks come with inherent advantages, they require regular maintenance. Since traditional construction materials deteriorate rapidly in the climatic conditions of this region, use of PVC based materials could be a viable option. In the design options presented, sun decks may be included as an optional feature that could readily be replaced with stairs leading to the outdoor.

Economic analysis for the Type 1a house, which was also used for the energy analysis, shows that a 7% return on investment could be expected from the front and back house design. This is a favorable percentage and would indicate a sound investment option. The back house also assists a great deal in paying for the mortgage, taxes, maintenance and insurance. Due to this, the owner would be required to pay as little as $129 per month to own the property. Assuming a mortgage of 80% on the front house, the annual investment required to own both the front and back houses was therefore shown to be $6,200. If, instead, a mortgage of 90% were to be placed on the front house, the total monthly cost for the infill property works out to be $302 with the annual investment to own the house standing at $14,500.

The initial investments to construct both the front and back houses are slightly on the higher side. A possible solution for this could be to build the house in different stages, wherein the front house is built first and then the back house is built from the rental income of the basement apartment along with additional personal investment. Today, with opportunities for up to 100% mortgages it might be possible to build the infill house given the monetary advantage of the rental income to pay for the mortgage. Hence, it can be concluded that building a back house is potentially a sound investment option that not only ensures monetary return but also serves a family's lifestyle flexibility.

The study presented a flexible housing solution in the context of Manhattan, Kansas. However, the design could be utilized in other locations as well subject to review and possible slight modifications to address local zoning regulations. Since the interior designs are already code compliant, they do not need to undergo any changes whatsoever. Moreover, on sites with similar orientation, bioclimatic design strategies employed herein would still be functional, adding to passive solar gains and hence reduction in utility bills.

Global environmental issues also needed to be answered along with flexibility by the designs proposed in the thesis. The design goal was to make the house sustainable given the fossil fuel crises and global warming issues plaguing humankind today. At the end of the study, a 'zero energy' design with reduction in energy needs by up to 60-65% for the front house and 50% for the back house was achieved. This was accomplished by increasing the efficiency of the overall building envelope. The thesis provides evidence that a well insulated structure can decrease the energy consumption of the building thereby saving on utility bills.

Hence, the thesis encourages one to build well insulated houses instead of making unnecessarily high investments on external finishes. A grid connected photo-voltaic system, would supplement harnessing of clean energy during the daytime. Along similar lines, a geothermal heat pump would also help in cooling and heating the house thus decreasing energy consumption.

This thesis gives a broad indication of the means and mechanisms to be implemented in one's pursuit of zero energy design in the Manhattan region. Every effort has been made to simulate conditions as close as possible to those pertaining to the actual site under study. However, it should be noted that the validity of the results of this study and simulations presented herein may not be 100%, primarily because the computer simulation programs used were designed for the state of California. Since the proposed design was connected to the grid it still had a carbon footprint.

The economic viability of the option to use solar panels was demonstrated by various calculations presented in Chapter 5. Although the initial investment was high in this case as well, reduced utility bills for the next 20 years could easily amount to savings that would pay off for the initial investment of $71,596, the PV system had a pay-back period of 15.9 years. Use of solar panels also meant use of a clean energy source and a reduced burden on the use of fossil fuels. The fact that it was grid connected means that one does not have to worry about battery storage, which is both expensive and also poses potential fire hazards.

The idea of using DC current for some of the appliances was considered, however its idea was aborted owing to the expensive wiring and the maintenance of such electric output points. Moreover, since it is proposed that the house be grid connected, AC wiring was preferable. If 'net metering' were to be introduced in Kansas, it could add to further gains on energy costs since the surplus energy could be sold back to the grid.

The economic analysis of the geothermal system was done using the best possible information available. However, the analysis assisted in estimating the economic benefits of using such systems and it also showed that the payback for this system could be as early as 2.5 years which is outstanding. As a clean and highly efficient energy source, it would certainly help reduce dependence on fossil fuel for heating and cooling. Use of energy efficient building components such as windows, doors and insulation as well as renewable energy systems resulted in tax credits of up to $14,000. This further supported the economic viability of the project.

In essence, this thesis addresses American lifestyle diversity through its assortment of proposed design options catering to a variety of household. The energy analysis helps in proposing a design for a more sustainable house that would use clean energy sources hence proactively addressing issues of global warming and the impending fossil fuel crisis. Finally, the economic analysis helps in understanding the financial aspects of building a front and back house as well as the economic feasibility of using renewable energy systems.

The thesis also tackled real life issues such as code compliance, estimates for the costs of building the front and back house as well as the cost of the renewable systems. Hence the thesis presents it readers with a comprehensive package wherein architectural design details, energy analysis and economic data for the front and back house design option is explored and documented. Furthermore, the author believes that the present study will be a platform for launching future exploration of design options for sustainable housing while also catering to the changing spatial needs of the present day American family.

References

1. Allen, Edward. 1999. *Fundamentals of Building Construction: Materials and Methods*. New York: John Wiley and Sons Inc.
2. American Institute of Architects. 2007. *Architectural Graphic Standards*, ed. Andrew Pressman. Seventh Edition ed. Hoboken, New Jersey: John Wiley and Sons Inc.
3. Balboni, Barbara, ed. 2008. *R.S Means: Square Foot Costs*. 29th Annual Edition ed. Kingston, MA.: Reed Construction Data Inc.
4. Balboni, Barbara, ed. 2008. *R.S. Means: Assemblies Cost Data*. 33rd. Annual Edition ed. Kingston, MA.: Reed Construction Data Inc.
5. Brown, G. Z., and Mark Dekay. 2001. *Sun, Wind and Light: Architectural Design Strategies*. Second ed. New York: James Wiley and Sons, Inc.
6. Building Officials and Code Administrators International. BOCA national building code International Conference of Building Officials. Uniform building code Standard building code, ed. 2006. *International Building Code 2006*. Falls Church, VA.: International Code Council.
7. Briscoe, Maphis, Murray, and Lamont, Inc. 1979. *Downtown Redevelopment Plan.* Boulder, Colorado: Briscoe, Maphis, Murray, and Lamont, Inc.
8. Coates, Gary J. 2007. *Bioregional Design Strategies*. Manhattan, Kansas: Kansas State University.
9. Coates, Gary J, ed. 2001. *Affordable Housing: Reweaving the fabric of Manhattan's Older Neighborhoods*. Manhattan, Kansas: Kansas State University.
10. Coates, Gary J, ed. 1981. *Resettling America: Energy, Ecology and Community*. Andover, Mass.: Brick House Pub. Co.
11. Dickson, Duo. 1995. *Small Houses for the Century*. New York: McGraw-Hill Inc.
12. Frederick, Lisa Gaddy. 2005. Better home better living: A home for all stages. *Better Homes and Gardens* (November): 190,191,192,193,194,195.
13. Friedman, Avi. 2002. *The Adaptable House: Designing Homes for Change*. New York: McGraw-Hill.
14. Gevorkian, Peter. 2006. *Sustainable Energy Systems in Architectural Design: A Blue Print for Green Buildings*. New York: McGraw-Hill.

15. Greene, Mary, ed. 2002. *Green Building: Project planning and cost estimating: A practical guide for constructing sustainable buildings*. Kingston, Mass.: R.S. Means.
16. Hayden, Dolores. 2002. *Redesigning the American Dream: The Future of Housing, Work and Family Life*. New York: W. W. Norton & Company.
17. Jones, Tom, William Pettus, and Michael Pyatok. 1995. *Good Neighbors: Affordable Family Housing*, ed. Sally B. Woodbridge. New York: McGraw-Hill.
18. Katz, Peter. 1994. *The New Urbanism: Towards an Architecture of Community*. New York: McGraw-Hill Inc.
19. Kelbaugh , Douglas S. 2002. *Repairing the American Metropolis*. Seattle: University of Washington Press.
20. McGlynn, Sue, Ian Bentley, Alan Alcock, Graham Smith, and Paul Murrain. 1985. *Responsive Environment: A Manual for Designers*. London: Architectural Press.
21. Ryker, Lori. 2005. *Off the Grid: Modern homes + Alternative energy*. Layton, Utah: Gibbs Smith.
22. Sarangapani, Harini. 2008. Zero Energy Garage Apartment. Master of Science in Architecture, Kansas State University.
23. Smith, Elizabeth A.T., comp.1989. *Blueprints for Modern Living: History and legacy of the case study houses*. Cambridge: The MIT Press.
24. Susanka, Sarah. 1998. *Not So Big House: A blueprint for the way we really live*. Newtown, CT: Taunton Press.
25. U.S Green Building Council. October 2005. *LEED-NC for new construction: Reference guide version 2.2*. First ed. Washington DC: U.S Green Building Council.
26. U.S Green Building Council. January 2007. *LEED for homes program pilot rating system: Version 1.11a*. Washigton D.C: U.S Green Building Council.
27. Yago, Jeffery R. 1999. *Achieving Energy Independence- One Step at a Time*. Gum Spring, Virginia: Duminis Technology Inc.

Websites:

1. 3/11/08]. Available from http://factfinder.census.gov/home/saff/main.html?_lang=en
2. 3/11/08]. Available from http://censtats.census.gov/data/KS/1602044250.pdf
3. 04/15/'07]. Available from http://gis.rileycountyks.gov/website/rileyco/viewer.htm
4. 4/24/'08]. Available from http://www.solartoday.org/2005/may_june05/ZEH.htm.
5. 2/24/'08]. Available from http://www.architecture2030.org/2030_challenge/index.html.
6. 2/24/'08]. Available from http://www.architecture2030.org/2030_challenge/index.html.
7. 04/25/ '07]. Available from http://www.epodunk.com.
8. 3/11/ '08]. Available from http://www.city-data.com/city/Manhattan-Kansas.html.
9. 3/11/ '08]. Available from http://www.ci.manhattan.ks.us.
10. 3/11/ '08]. Available from http://www.ci.manhattan.ks.us/DocumentView.asp?DID=2597.
11. 3/11/ '08]. Available from http://www.city-data.com/city/Manhattan-Kansas.html.
12. 3/11/ '08]. Available from http://www.ci.manhattan.ks.us/DocumentView.asp?DID=2598
13. 3/11/ '08]. Available from http://www.ci.manhattan.ks.us/DocumentView.asp?DID=2598.
14. 04/15/ '07]. Available from http://www.ci.manhattan.ks.us/common/modules/documentcenter2/documentview.asp?DID=1650.
15. 3/13/ '08]. Available from http://www.ci.manhattan.ks.us/index.asp?nid=491.
16. 3/11/ '08]. Available from http://www.ci.manhattan.ks.us/DocumentView.asp?DID=2597.
17. 3/13/ '08]. Available from http://www.ci.manhattan.ks.us/index.asp?NID=493.
18. 3/13/ '08]. Available from http://www.ci.manhattan.ks.us/index.asp?NID=493
19. 3/11/ '08]. Available from http://www.ci.manhattan.ks.us/index.asp?NID=493.
20. 4/10/ '08]. Available from http://www.nrel.gov/buildings/energy10.html.
21. 4/10/ '08]. Available from http://www.sbicouncil.org/store/e10.php.

22. 05/05/‘08]. Available from http://www.taunton.com/finehomebuilding/how-to/articles/understanding-energy-efficient-windows.aspx.
23. 05/02/ ‘08]. Available from http://www.scsolar.com/Batteries.html.
24. 04/12/ ‘08]. Available from http://www.cel-f-solar.com/images/PV-GridSystem.jpg.
25. 01/20/‘08]. Available from http://www.scsolar.com/UniSolar.html.
26. 03/12/‘08]. Available from http://www.xantrex.com/support/gtsizing/index.asp?lang=eng#calculator.
27. 03/21/‘08]. Available from http://www.altersystems.com/catalog/gridtie-inverters-xantrex-gt-inverters-c-1_5_117.html?sort=3d&page=1.
28. 04/01/‘08]. Available from http://www.geoecs.com/geothermal_how_it_works.html.
29. 03/20/‘08]. Available from http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12660.
30. 05/04/‘08]. Available from http://www.envirotechgeothermal.com/geothermal_advantages.html.
31. 4/05/ ‘08]. Available from http://www.westarenergy.com.
32. 04/05/‘08]. Available from http://www.energystar.gov/index.cfm?c=products.pr_tax_credits#s1.
33. 05/05/’08]. Available from http://www.newurbanism.org/newurbanism/principles.html.
34. 04/02/’08]. Available from http://www.joemaggio.com/r_mortgage-calculator_rentvsbuy.asp.
35. 04/02/’08]. Available from http://www.joemaggio.com/r_mortgage-calculator_rentvsbuy.asp.
36. 04/02/’08]. Available from http://www.rileycountyks.gov/documents/County%20Clerk/Mill%20Levy%20Sheets/LevyCertification%20Tax%20Units.pdf.
37. 04/02/’08]. Available from http://gis.rileycountyks.gov/website/rileyco/viewer.htm.
38. ADA and ABA accessibility guidelines. 01/20/'08]. Available from http://www.jan.wvu.edu/links/adalinks.htm#guidelines.
39. 4/05/’08]. Available from http://photovoltaics.sandia.gov/docs/LCcost.htm.

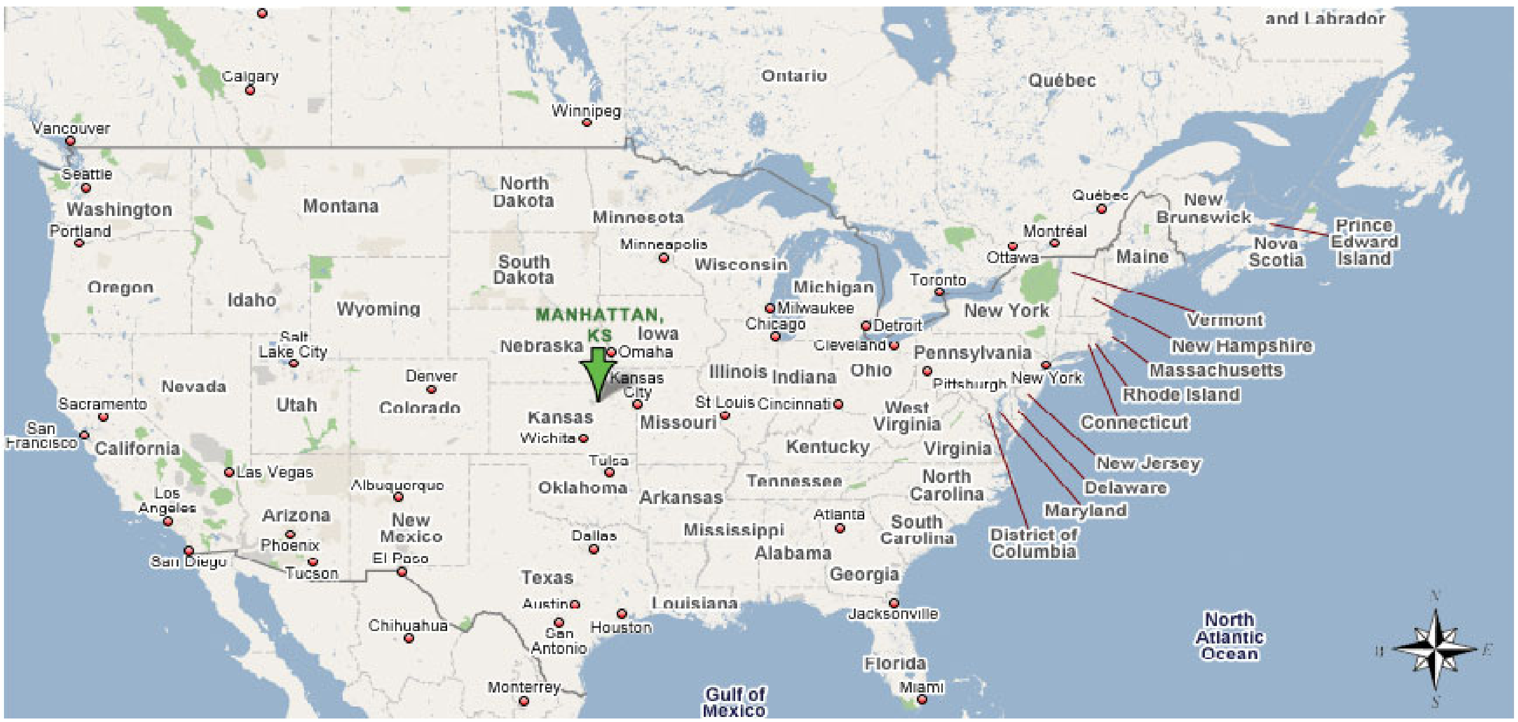
40. 4/07/'08]. Available from http://store.altenergystore.com/Inverters/On-Grid-Grid-Intertie-No-Batteries/4001-TO-7500-Watts/Xantrex-GT50KW-240208V-Grid-Tie-Inverter/p5846/?source=froogle.
41. 04/03/'08]. Available from http://www1.eere.energy.gov/geothermal/pdfs/26161b.pdf.
42. 09/01/'08]. Available from http://www.guardian.co.uk/business/2008/jun/13/inflation.usa
43. 09/22/'08]. Available from http://www.infinitepower.org/ home-eem.htm

Appendix A - Manhattan, Kansas

Figure A.1 shows the location of the city of Manhattan in the map of USA. Manhattan, Kansas was the site for the study in the thesis.

Figure A.1 Location map of Manhattan, Kansas

(Source: http://maps.google.com/maps: 04/29/’08)



Appendix B - Design Matrix Documentation

This appendix provides the documentation of the remaining design of the various types of houses described in the Design Matrix in Chapter 3. The appendix includes the description of house Types 1b-1d, 2b-2d and 3a, 3c &3d.

Type 1b House

The proposed design elevates the back house to a two storey house with an accessible tornado shelter located in the front house basement. A sun room has been added in the back house increasing the area of the back house apartments to 1,380 sf. each. The total area of the front house is 2,600 sf with an 850 sf basement rental unit. The front house has a sun-deck to the south. Since the back house is elevated, the front house receives less solar access.

Figure B.2 1b Location Plan

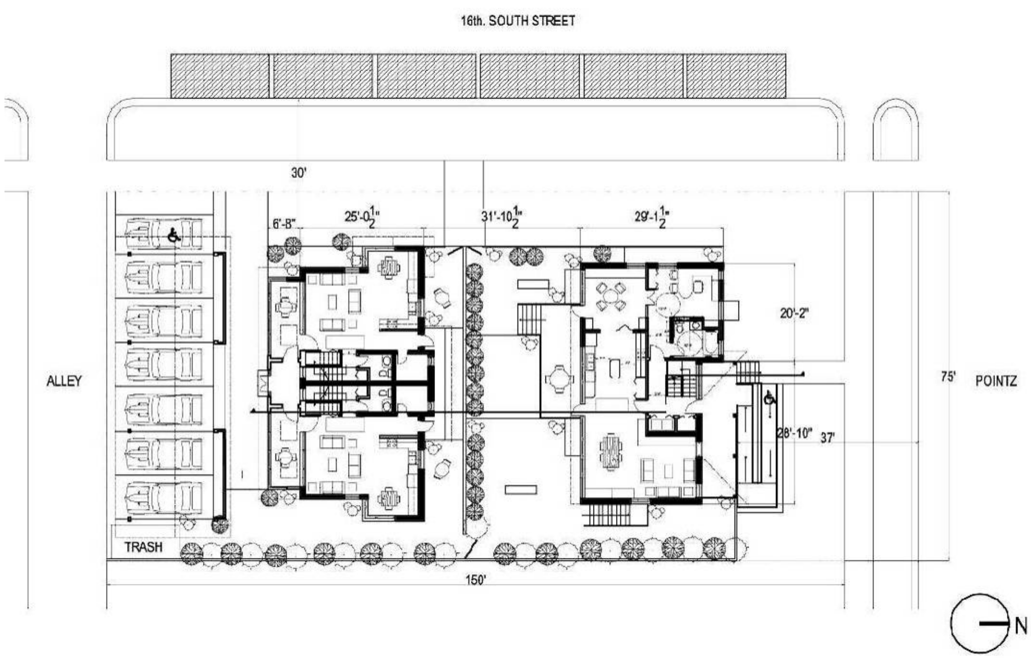


Figure B.3 1b First Floor Plan

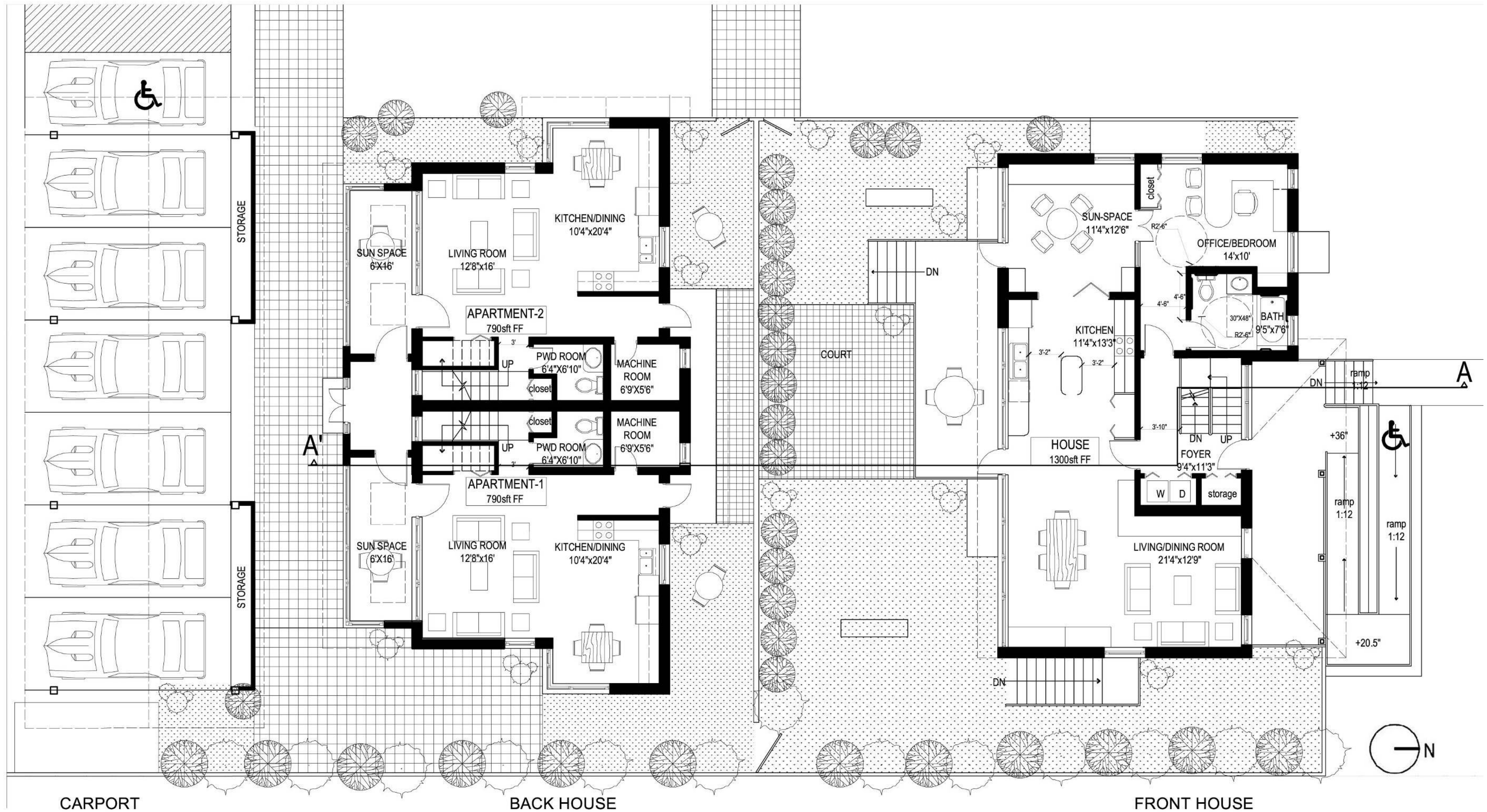


Figure B.4 1b Second Floor Plan

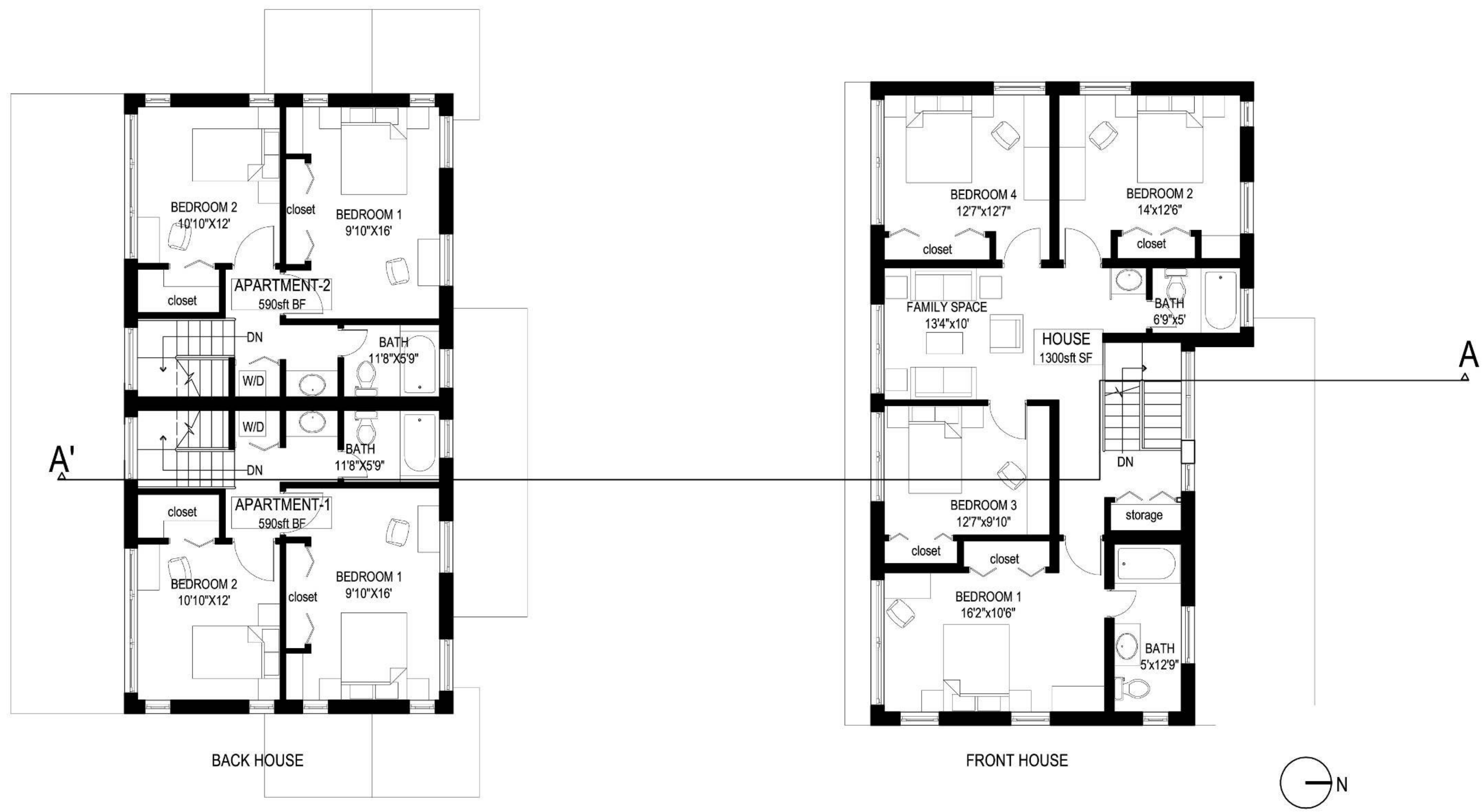


Figure B.5 1b Basement Floor Plan

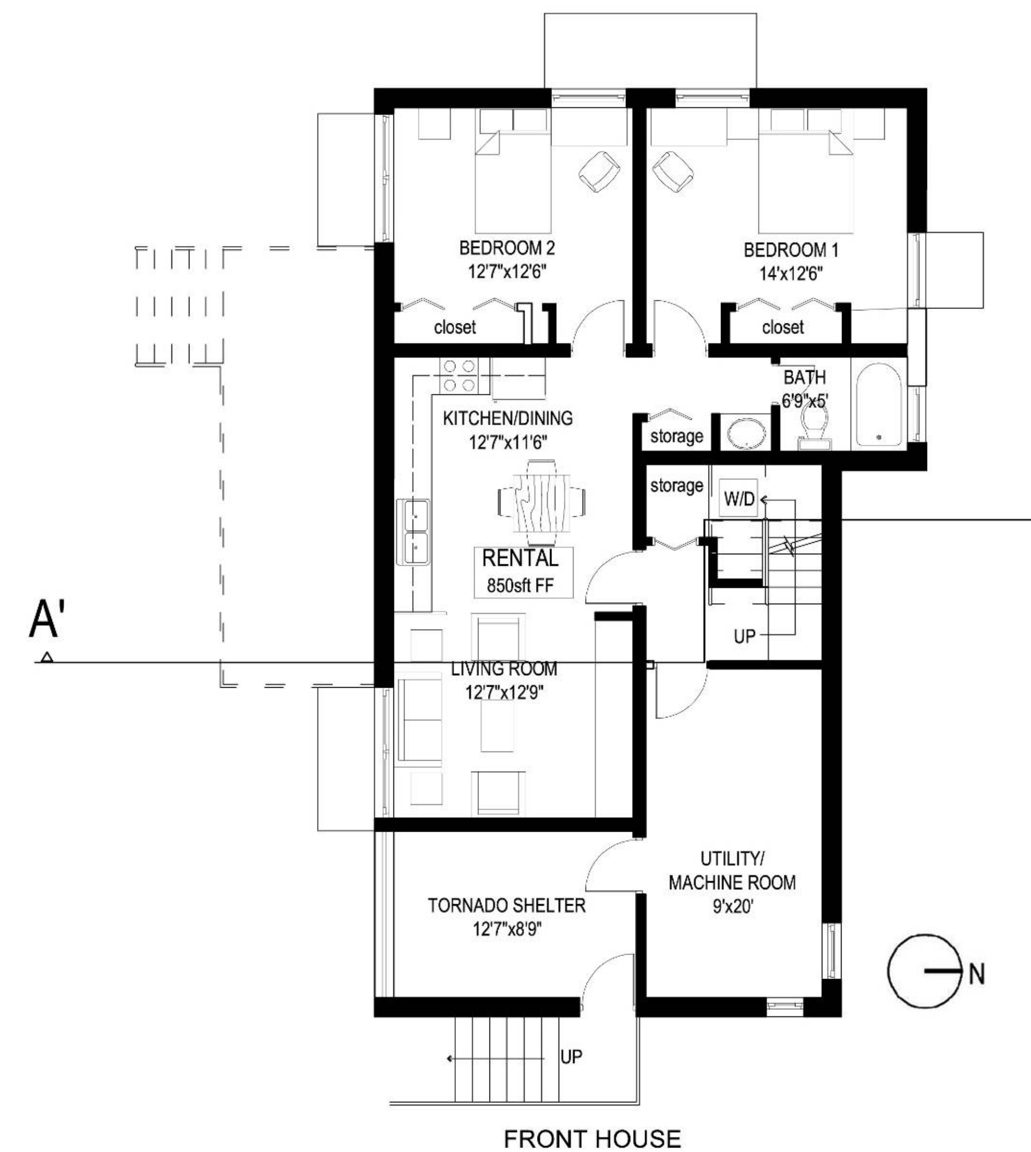


Figure B.6 1b Section AA’

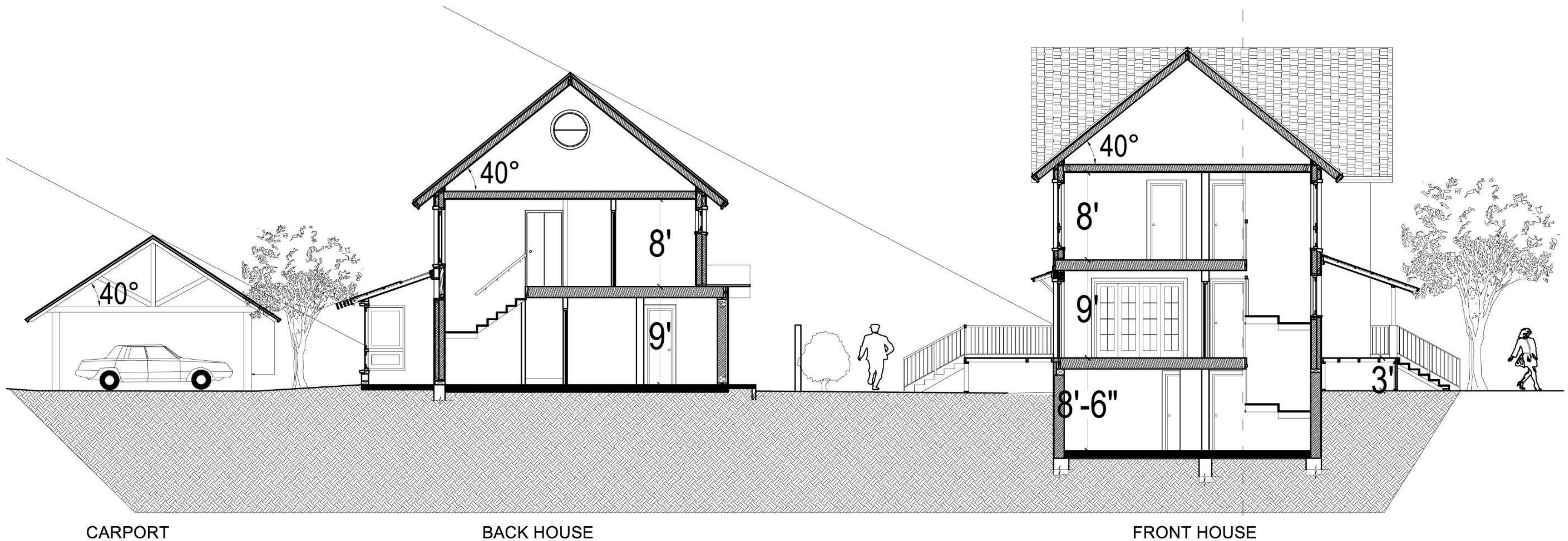


Figure B.7 1b South and North Elevation

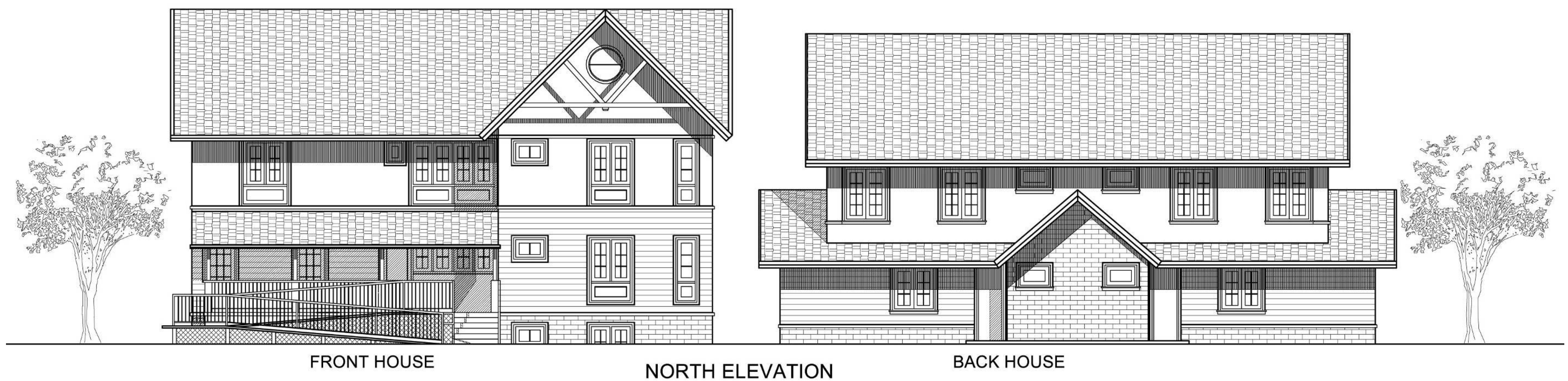
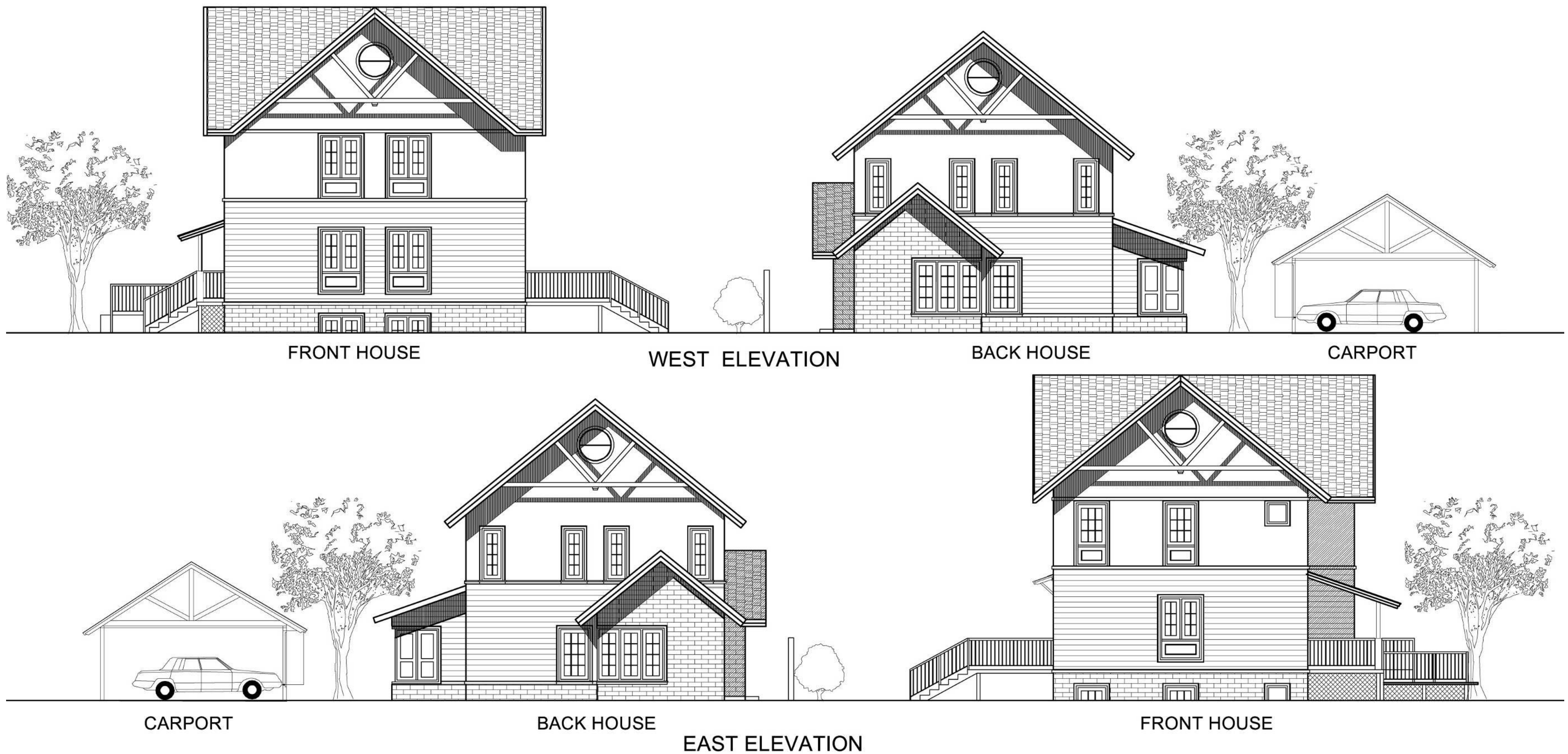


Figure B.8 1b West and East Elevation



Type 1c House

The proposal is similar to Type 1b. However, in this case, a small sun room has been added on the back yard of the front house and the back house has a sun- deck. The total area of the front house is 2,788 sf with an 850 sf basement rental unit. The total area of the back house rental unit is 1,232 sf.

Figure B.9 1c Location Plan

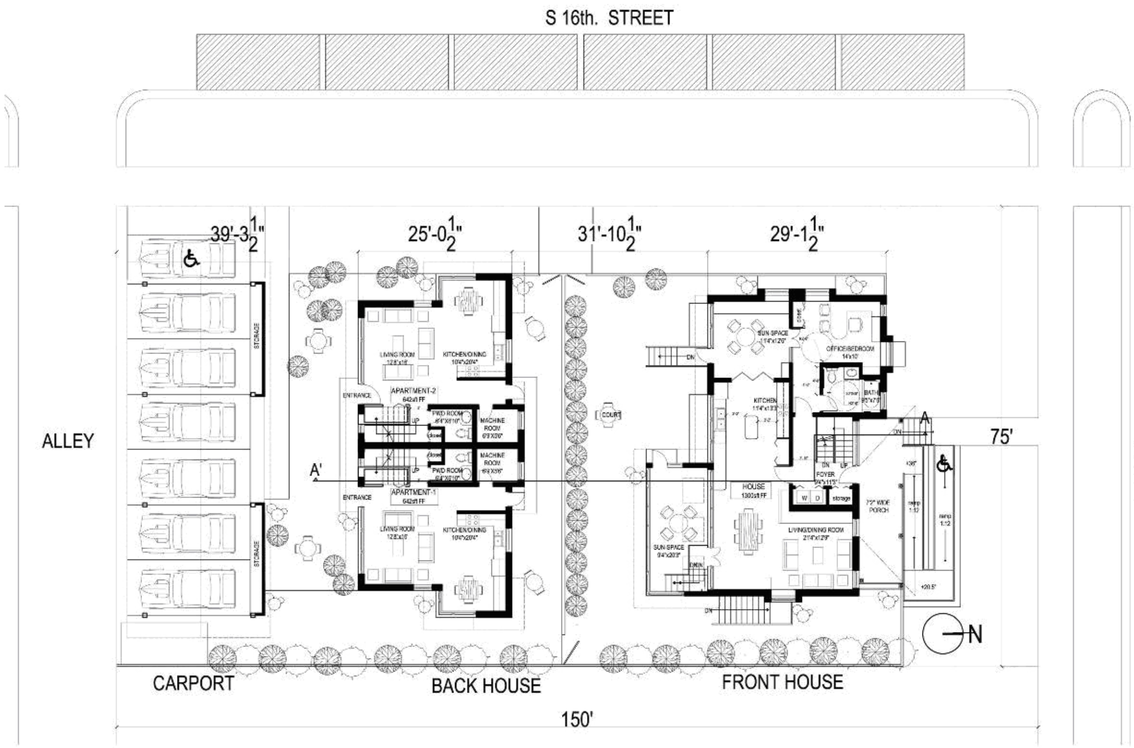


Figure B.10 1c First Floor Plan

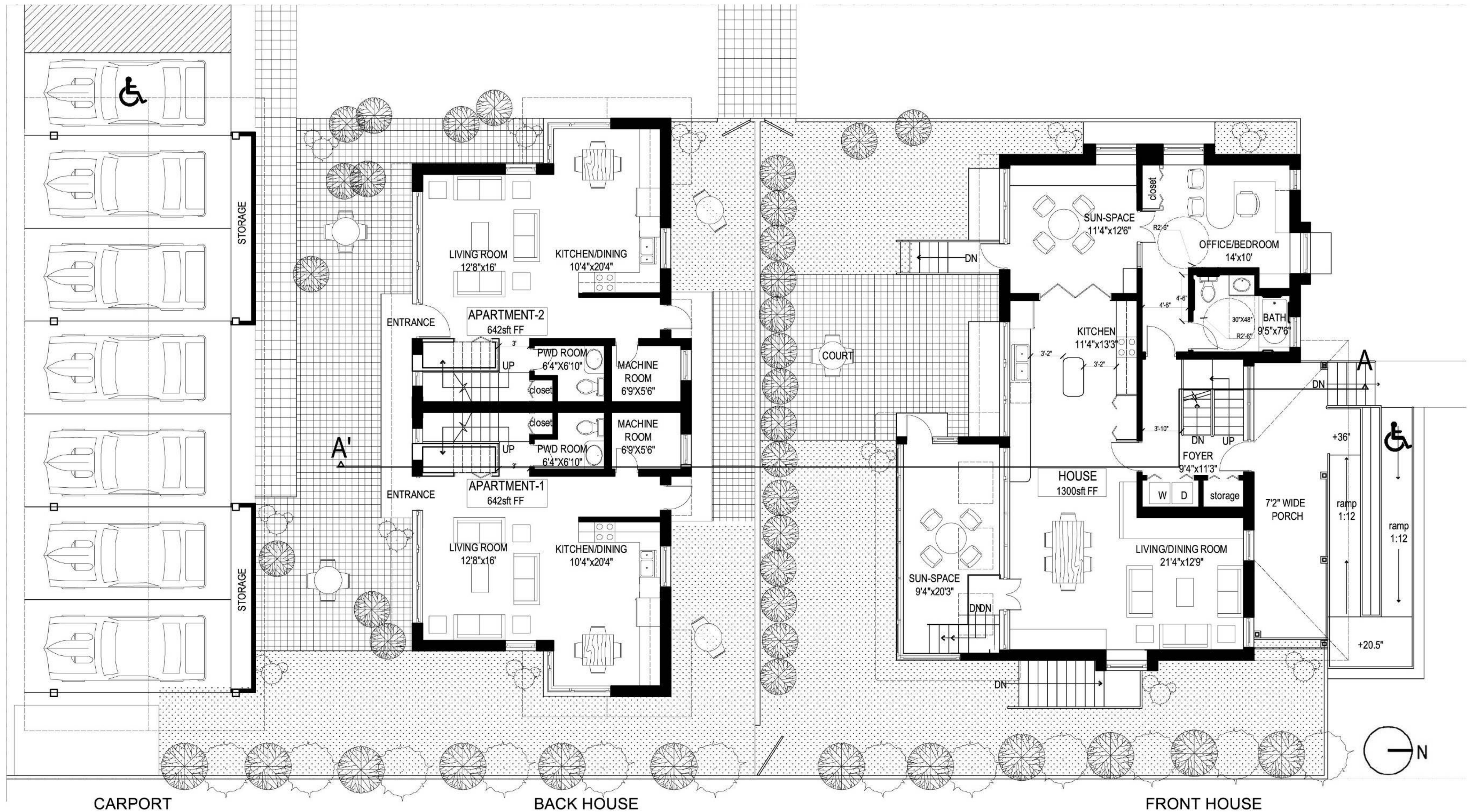


Figure B.11 1c Second Floor Plan

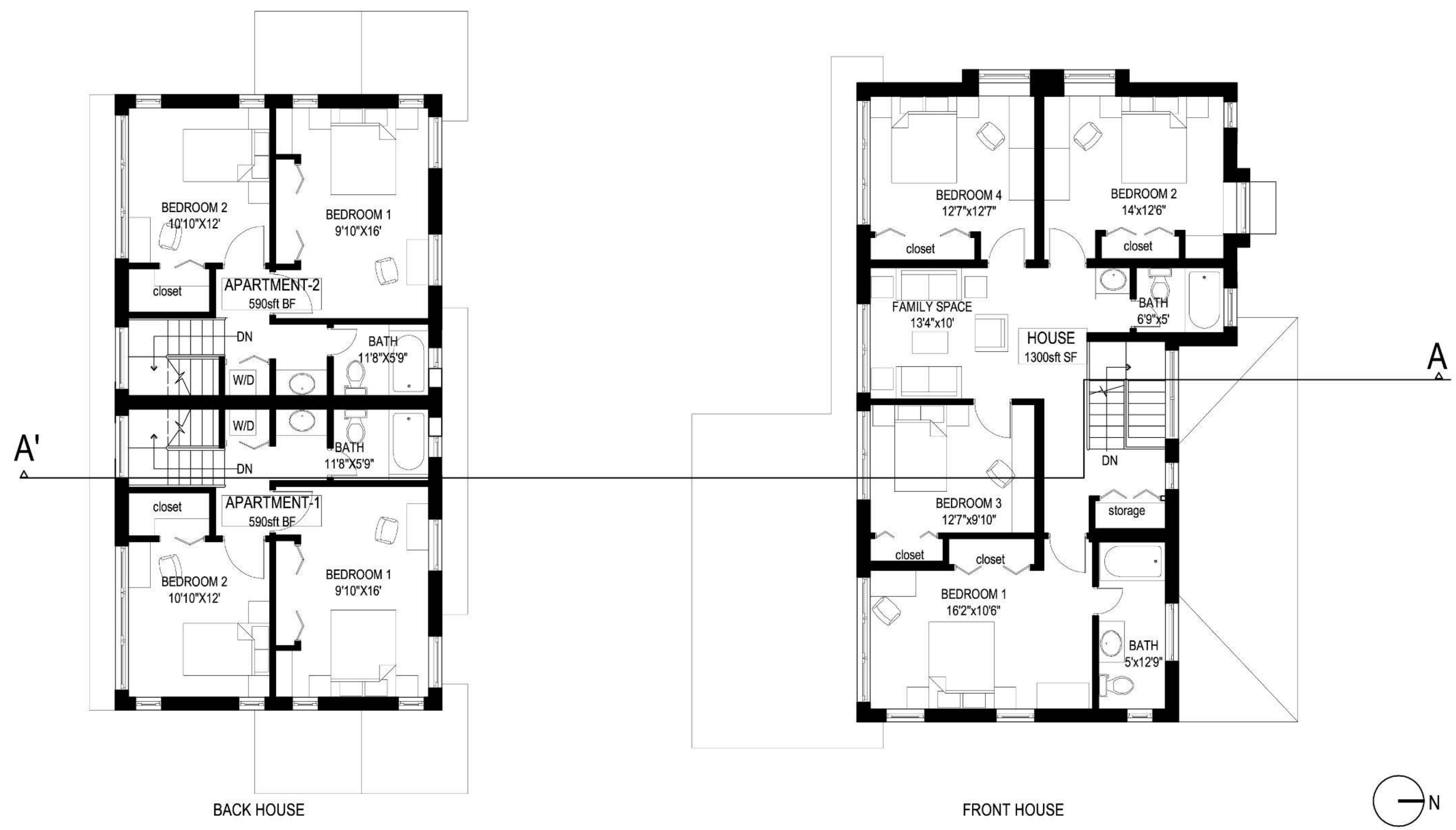


Figure B.12 1c Basement Floor Plan

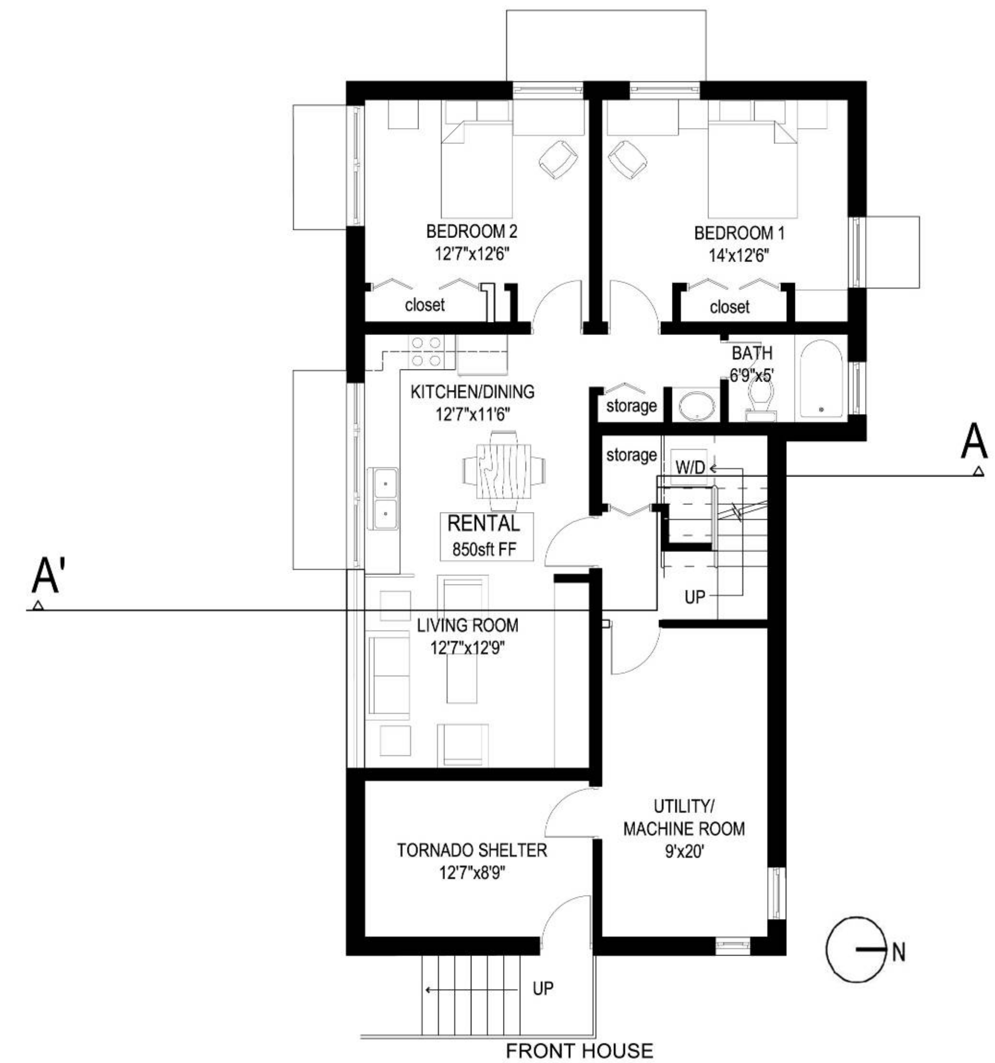


Figure B.13 1c Section AA’

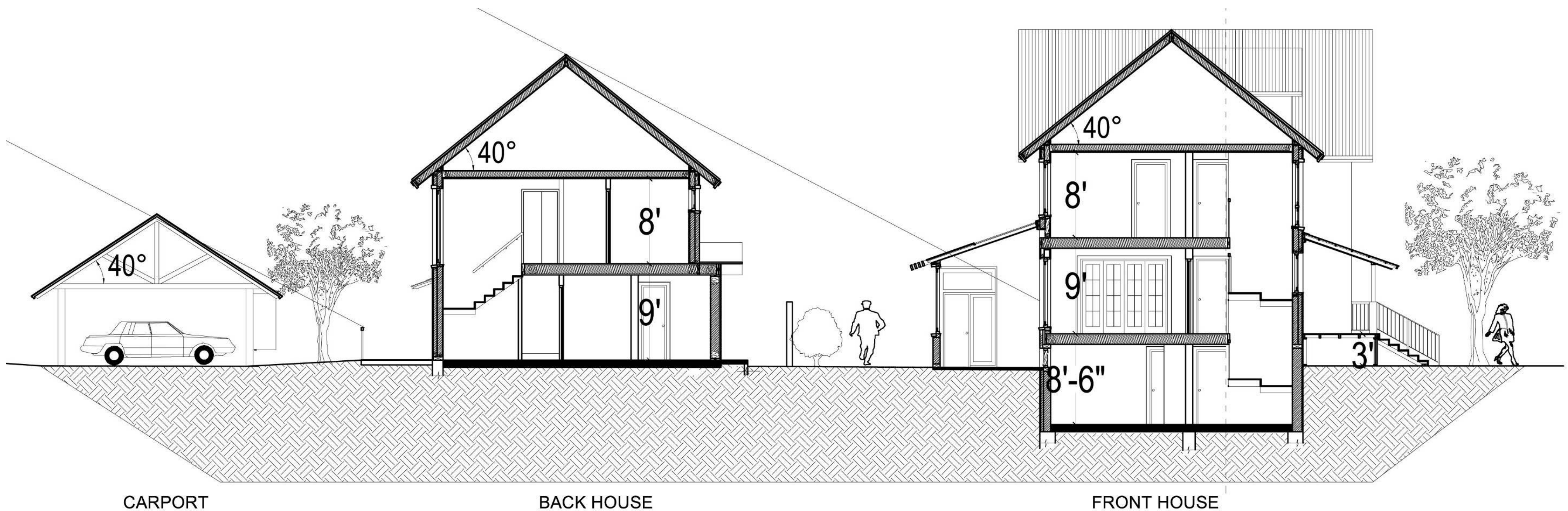
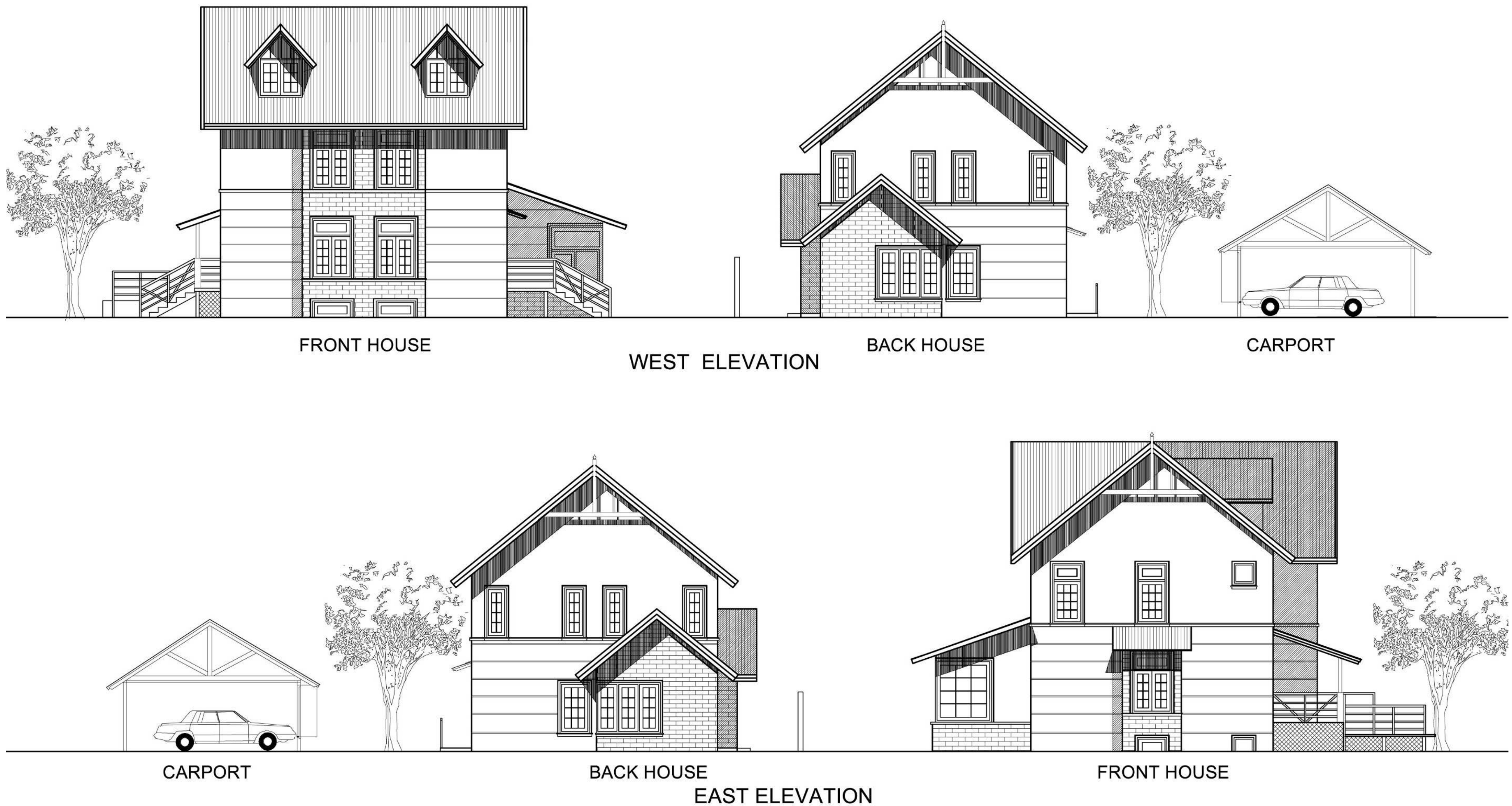


Figure B.14 1c South and North Elevation

Figure B.15 1c West and East Elevation



Type 1d House

The architectural design for Type 1d is similar to Type 1a. The back house is integrated into the ground and each apartment has a total area of 1,230 sf. The back house has a sun-deck. The front house increases in area due to the addition of a long sunspace running along the entire length of its south wall. The area of the front house is 3,000 sf with an 1,100 sf basement apartment. There is no tornado shelter in this design since both the houses have basements.

Figure B.16 1d Location Plan

Figure B.17 1d First Floor Plan

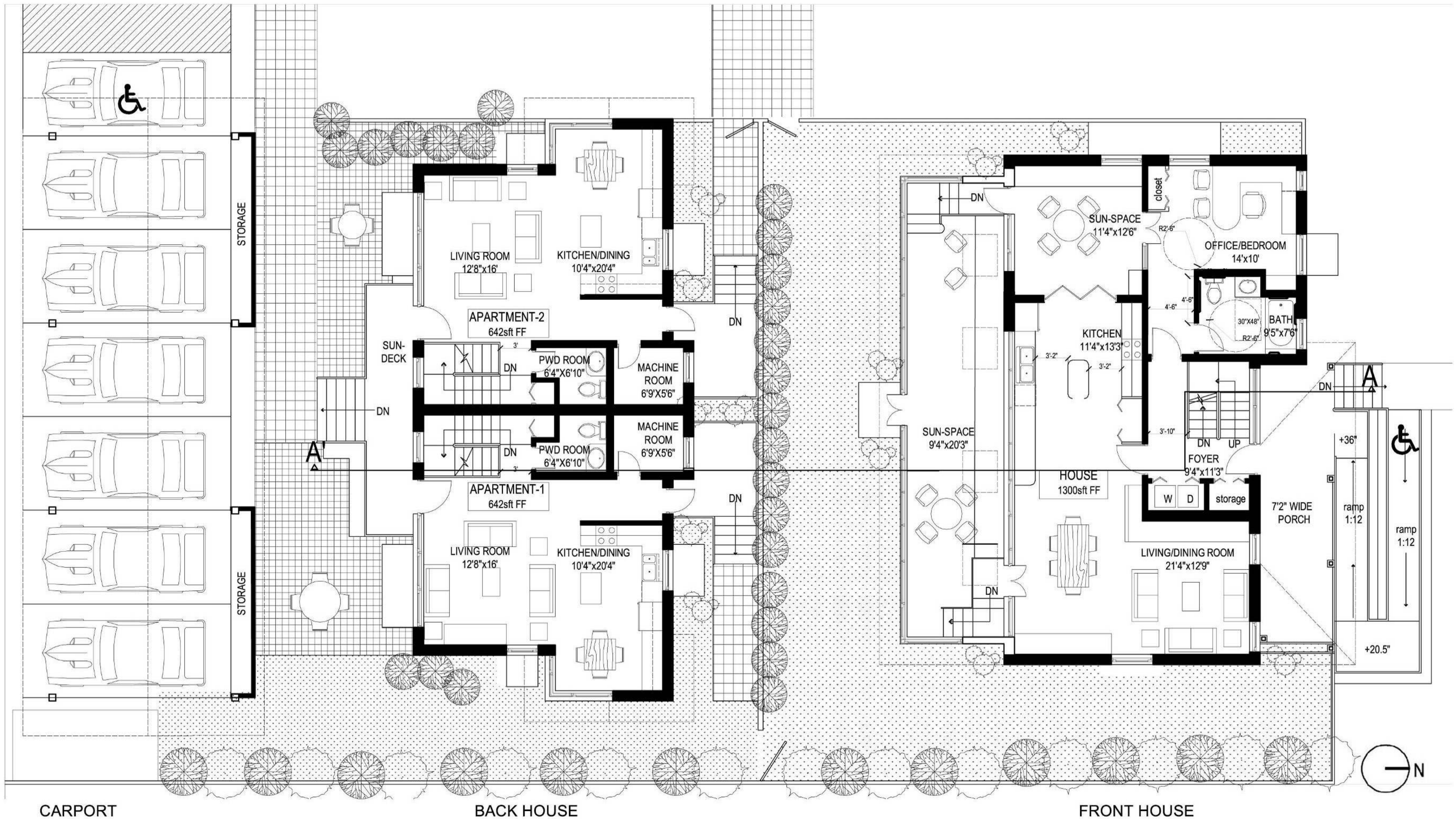


Figure B.18 1d Second Floor Plan

Figure B.19 1d Basement Floor Plan

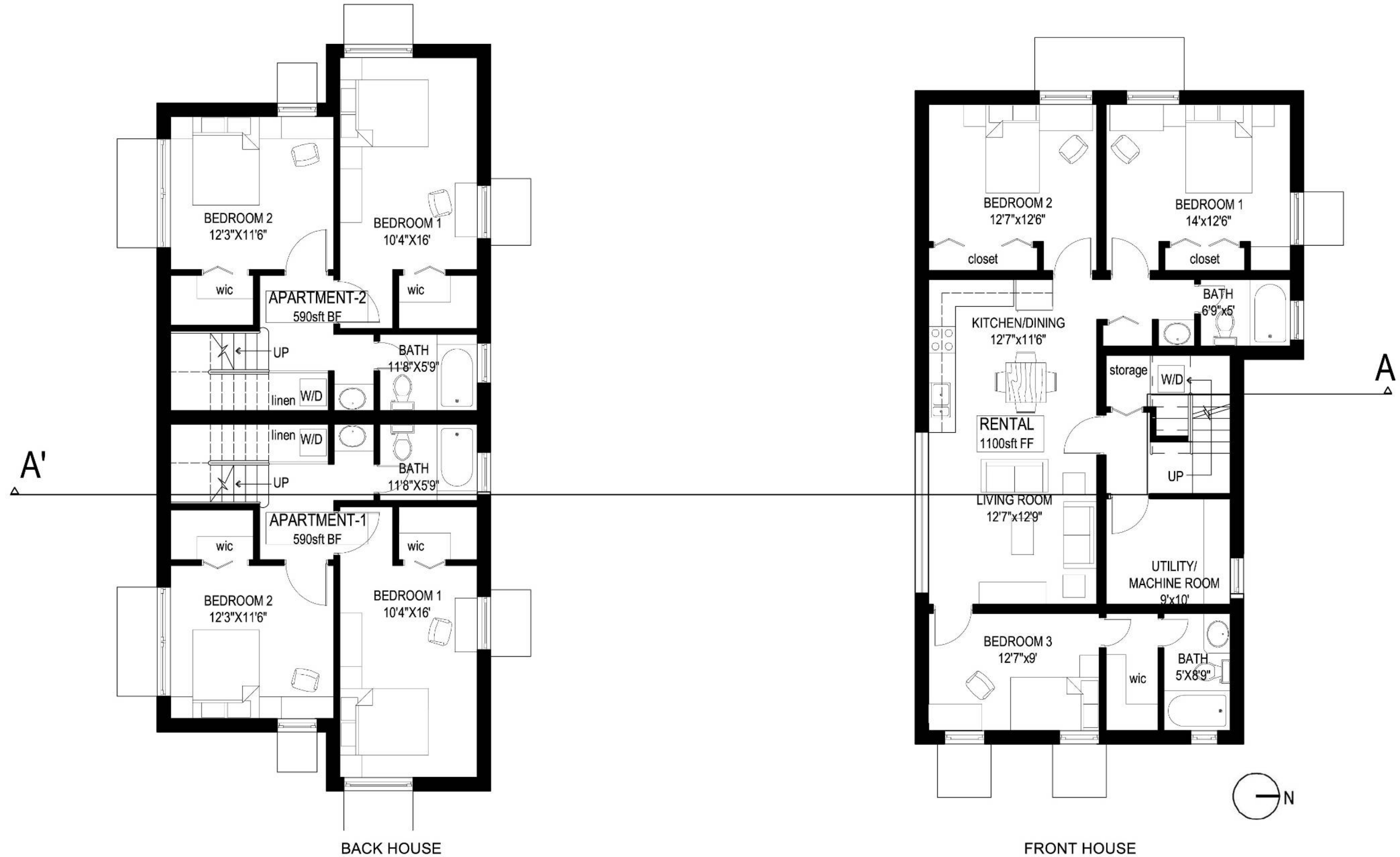


Figure B.20 1d Section AA'

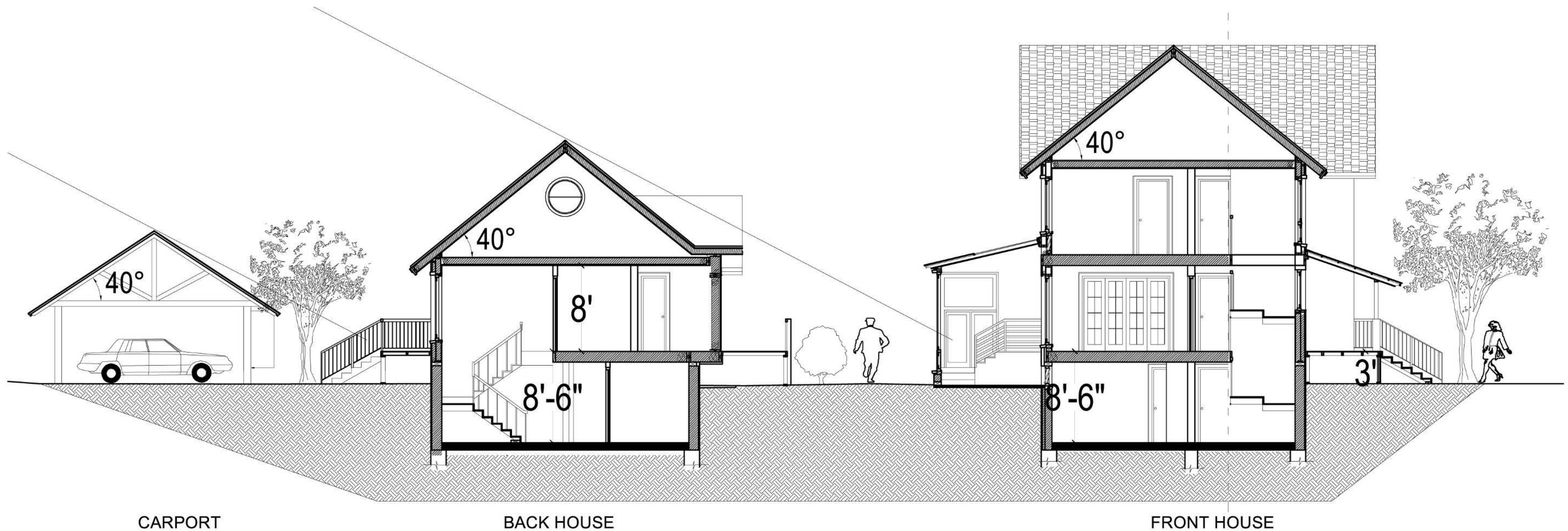
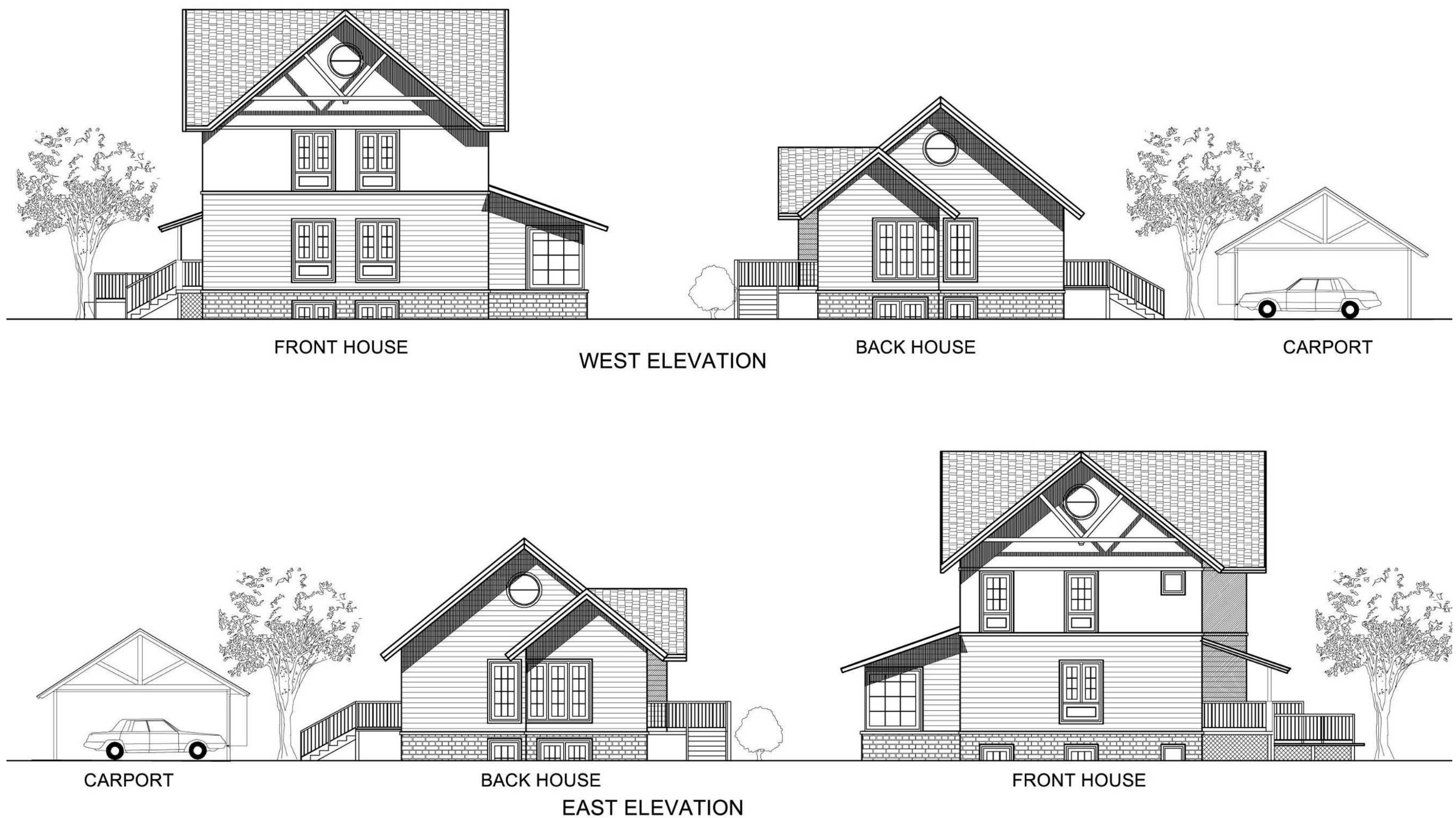


Figure B.21 1d South and North Elevation

Figure B.22 1d West and East Elevation



Type 2b House

In this case both the front and back house have a sun decks and the back house has a basement floor and a first floor. The area of the front house first floor is 1,300 sf, second floor rental is 1,300 sf and the basement apartment is 1,100 sf. The back house is 1,230 sf each. All the other features follow the lines of the preceding designs.

Figure B.23 2b Location Plan

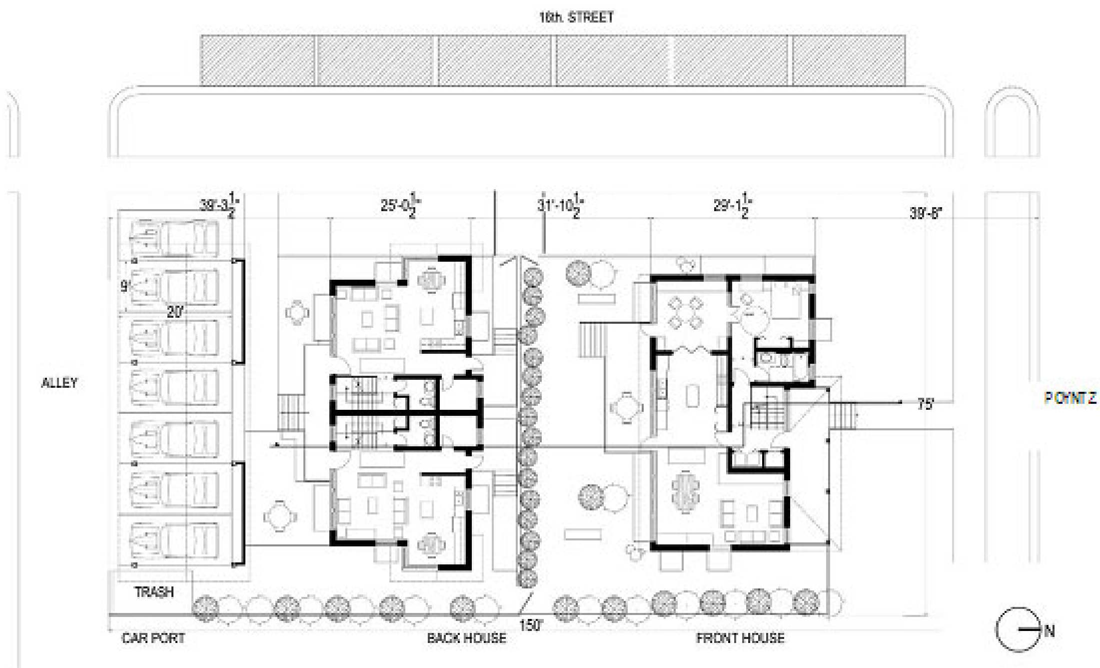


Figure B.24 2b First Floor Plan

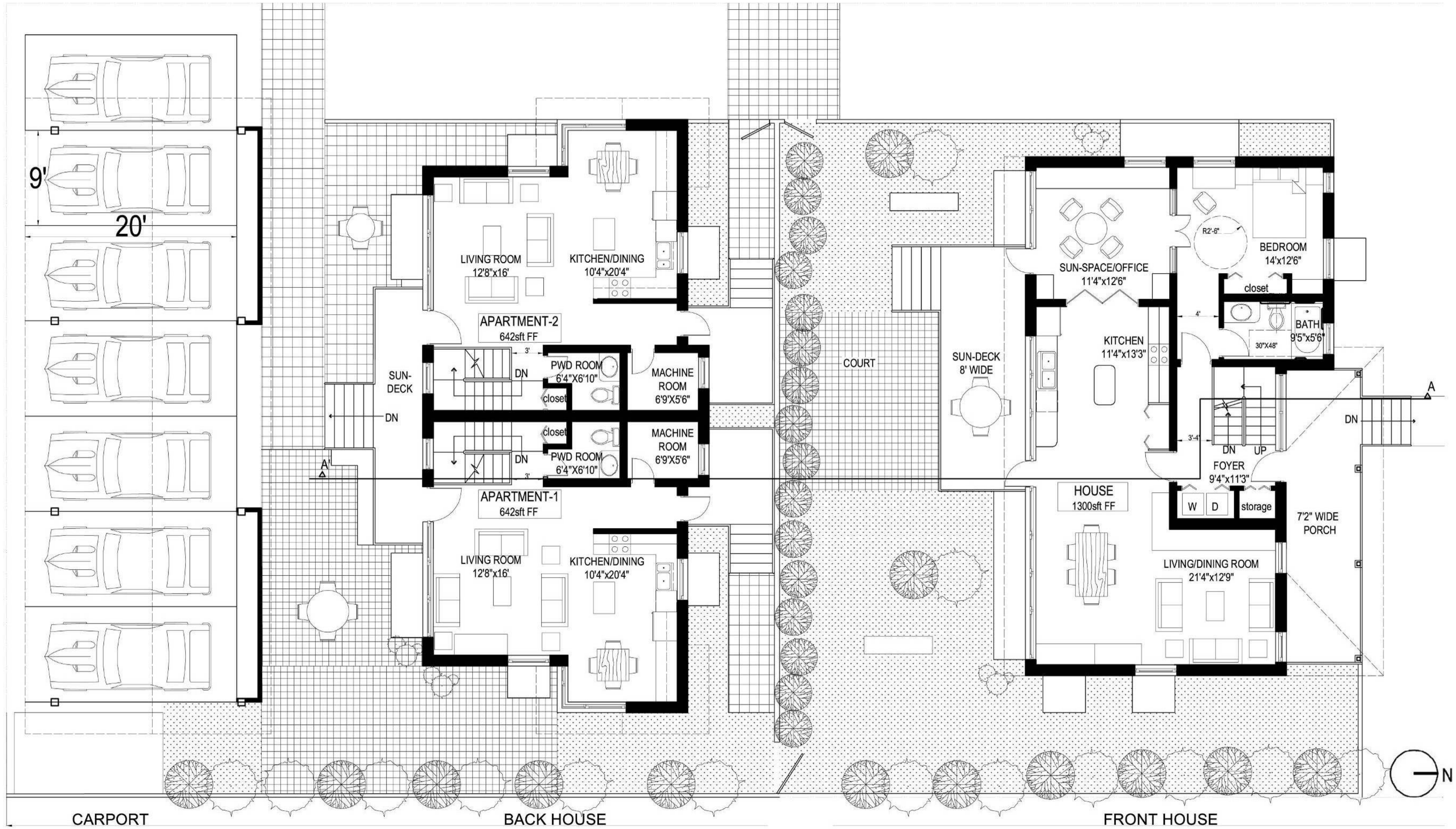


Figure B.25 2b Second Floor Plan

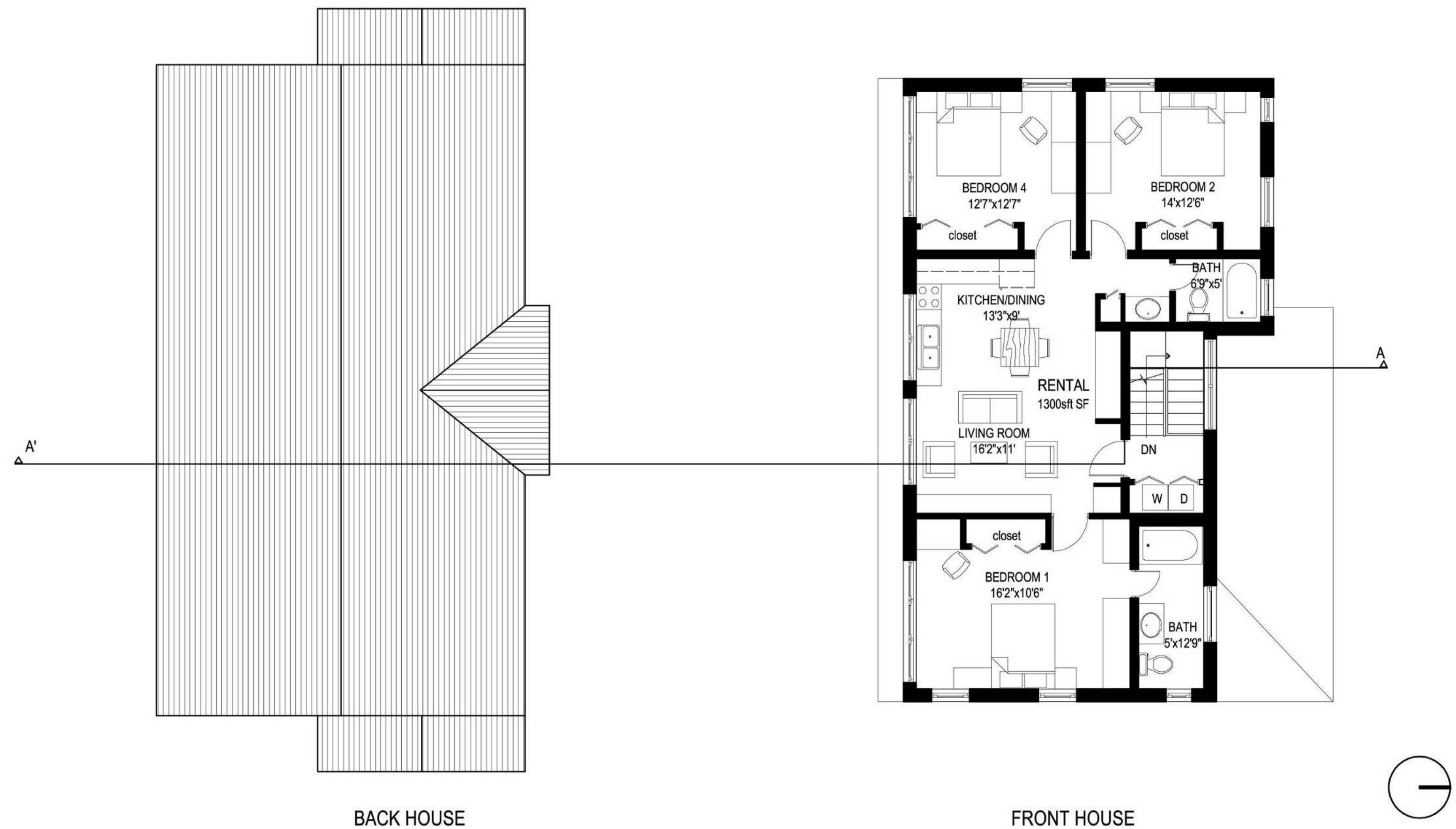


Figure B.26 2b Basement Floor Plan

Figure B.27 2b Section AA'

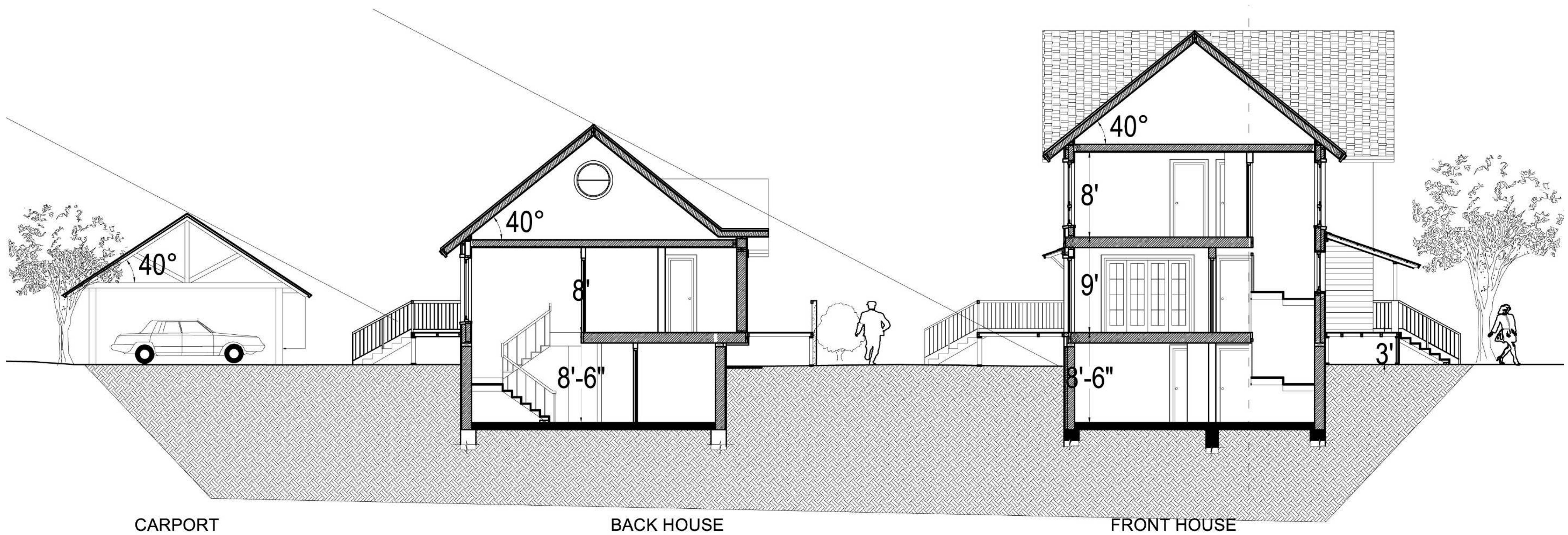
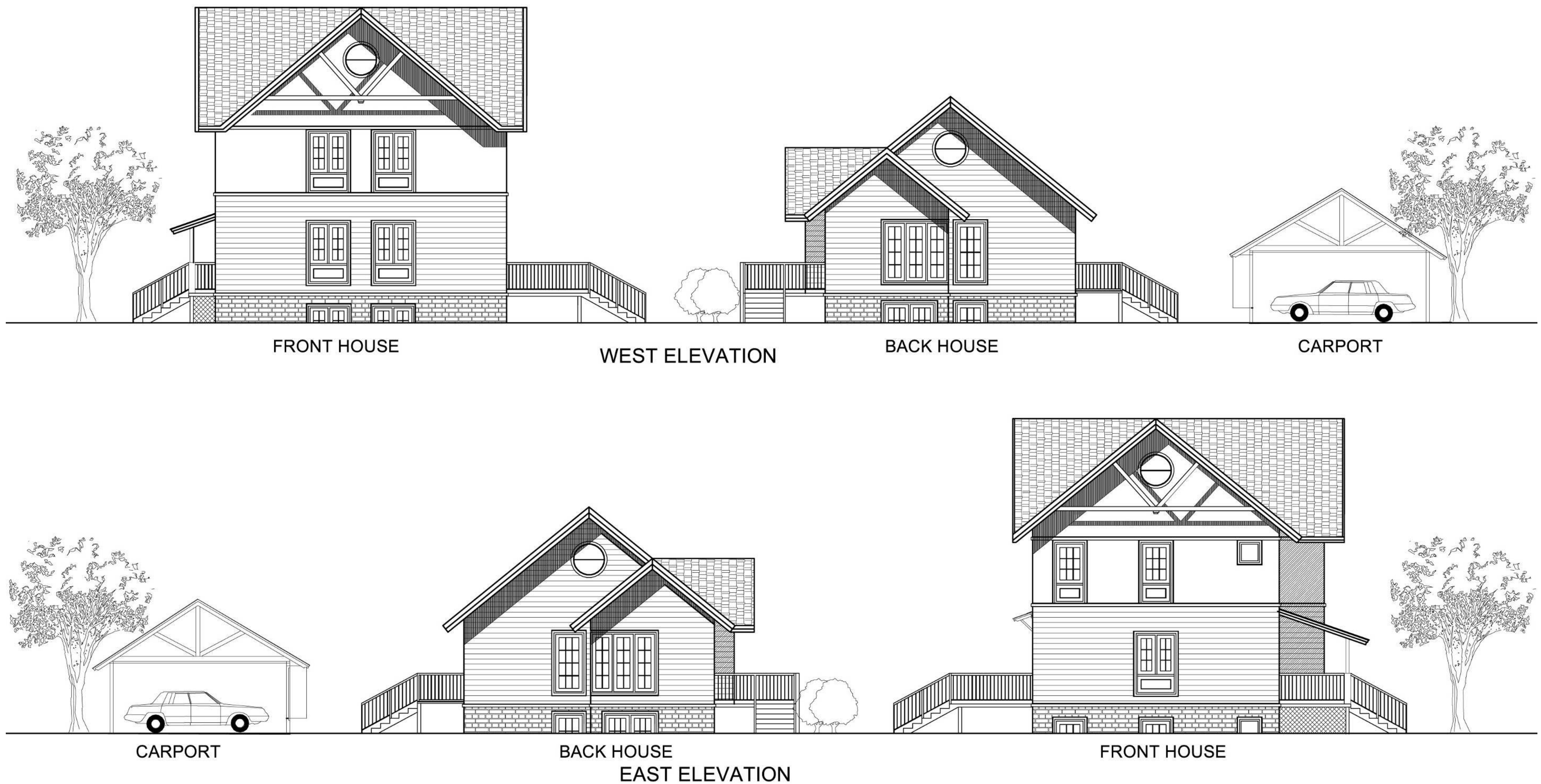


Figure B.28 2b South and North Elevations

Figure B.29 2b West and East Elevations



Type 2c House

A long sun space (408 sf.) has been added to the south wall of the front house. The sunspace has ventilators to the first floor and basement floors for circulation of warm air and its roof has vents for ventilation. The total area of first floor is1,600 sf, second floor rental is 1,300 sf and the basement apartment is 1,100 sf. The back house is 1,230 sf each and has a sun deck on the first floor with bed rooms in the basement floor.

Figure B.30 2c Location Plan

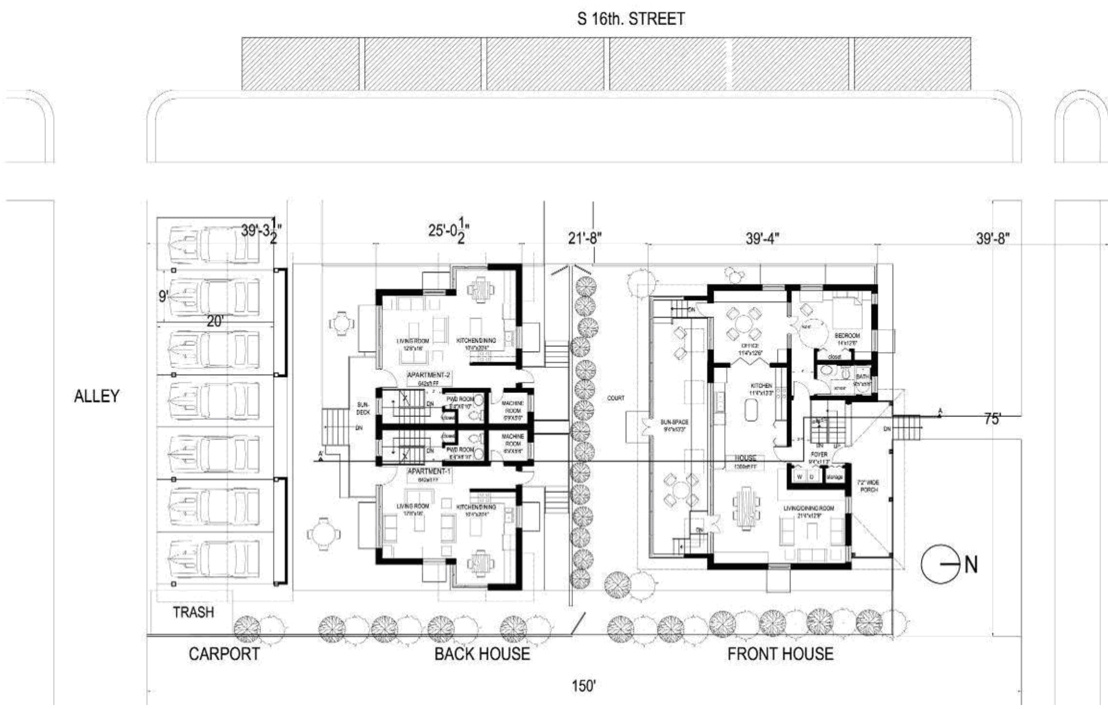


Figure B.31 2c First Floor Plan

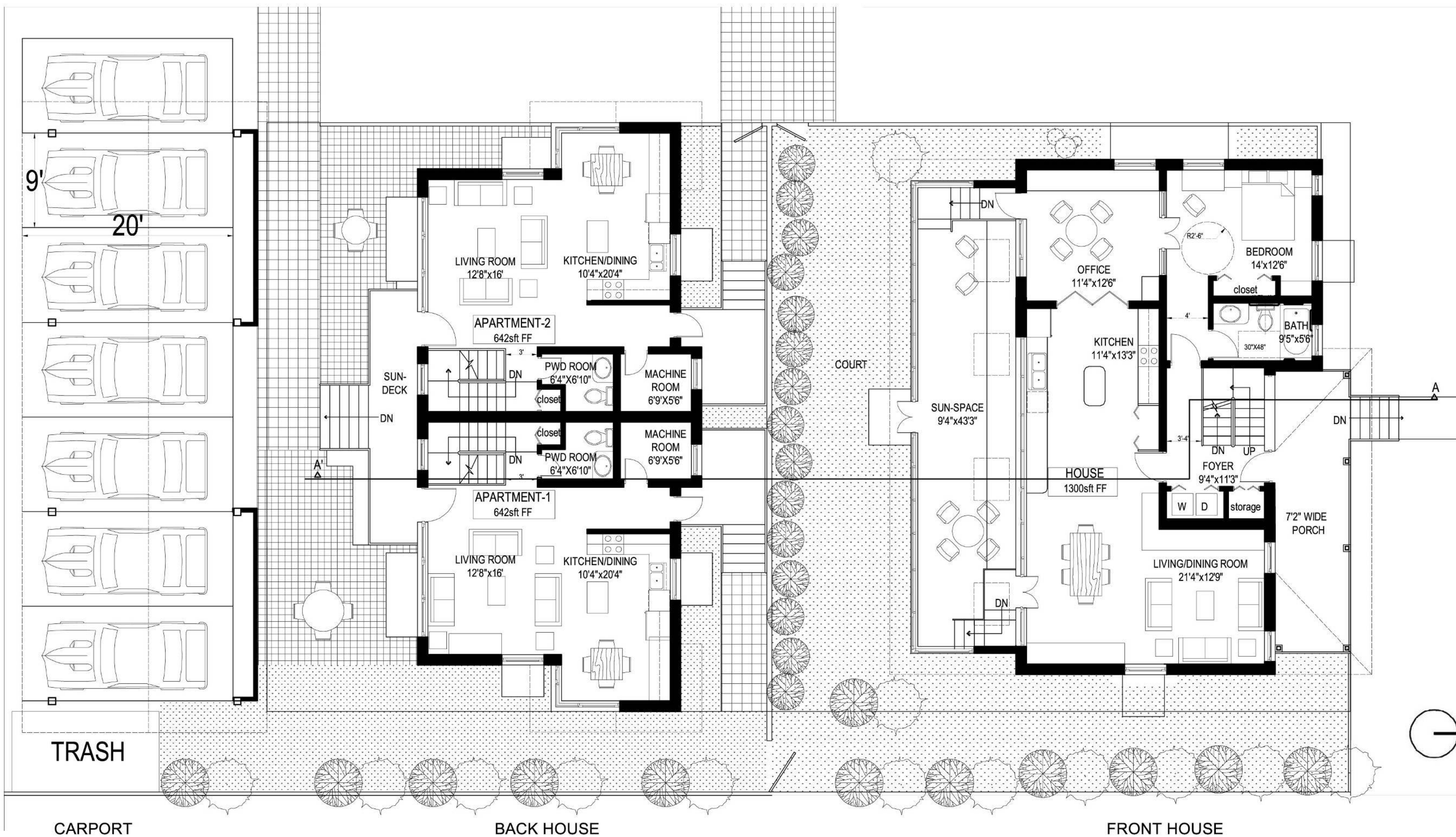


Figure B.32 2c Second Floor Plan

Figure B.33 2c Basement Floor Plan

Figure B.34 2c Section AA’

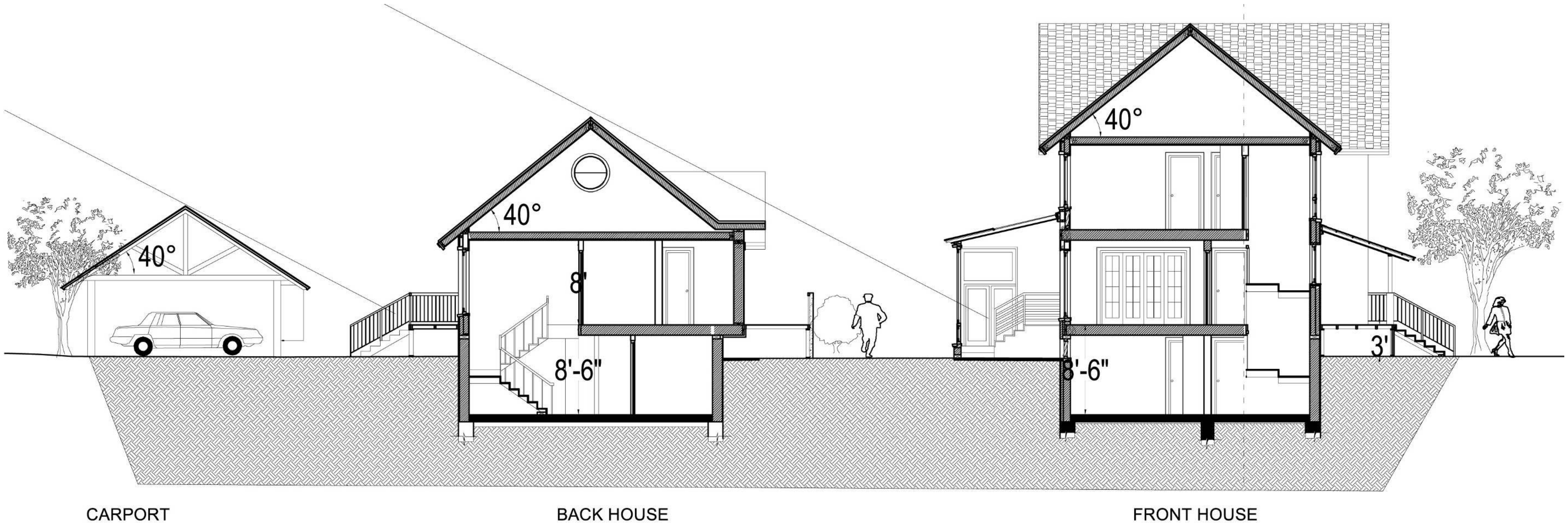
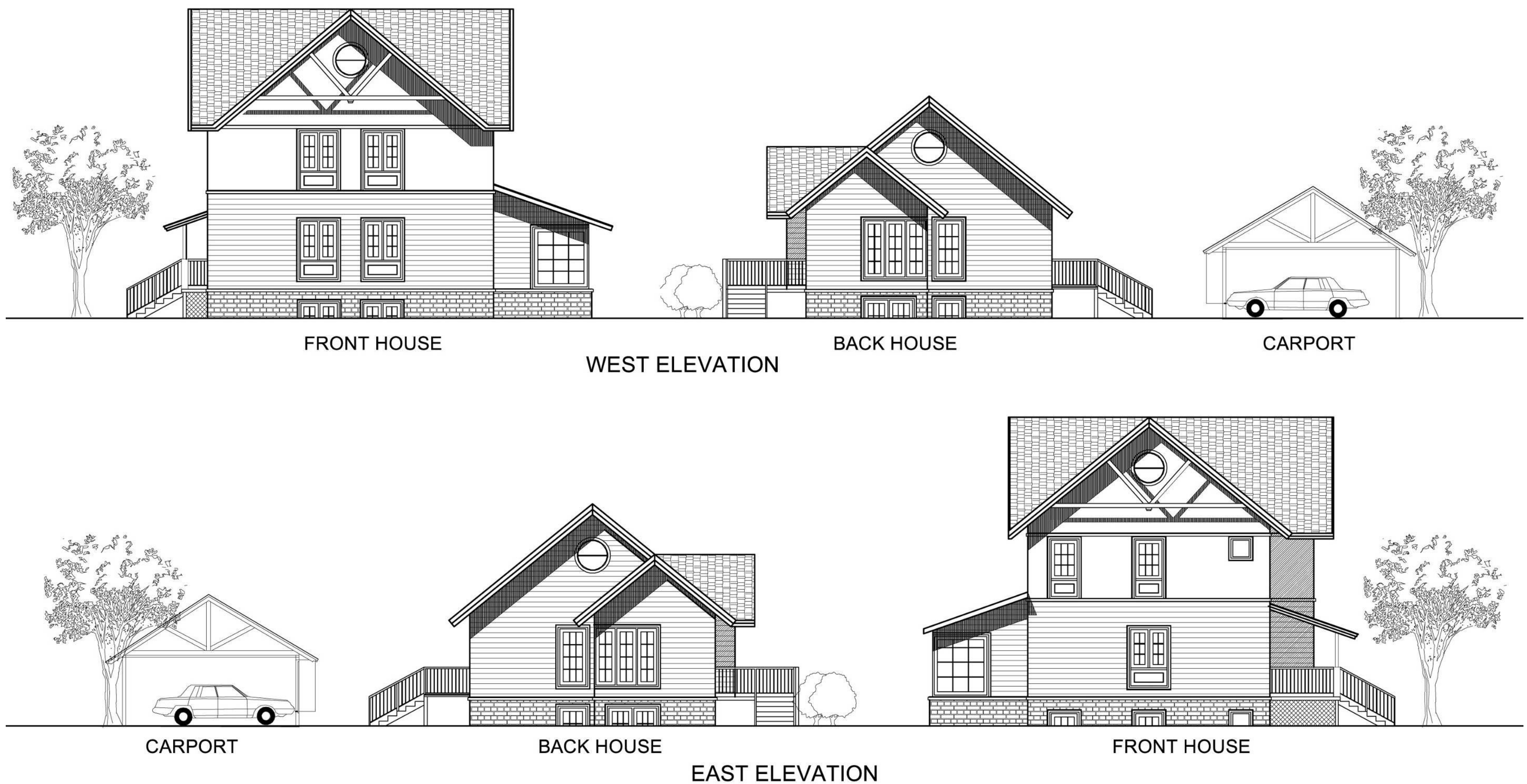


Figure B.35 2c South and North Elevation

Figure B.36 2c West and East Elevation



Type 2d House

In this case the sun space is shorter (190 sf.) in the front house. The total area of first floor is1,450 sf, second floor rental is 1,300 sf and the basement apartment is 850 sf and it has a tornado shelter for the complex. The back house is 1,230 sf each and has a sun deck on the first floor with bed rooms in the second floor.

Figure B.37 2d Location Plan

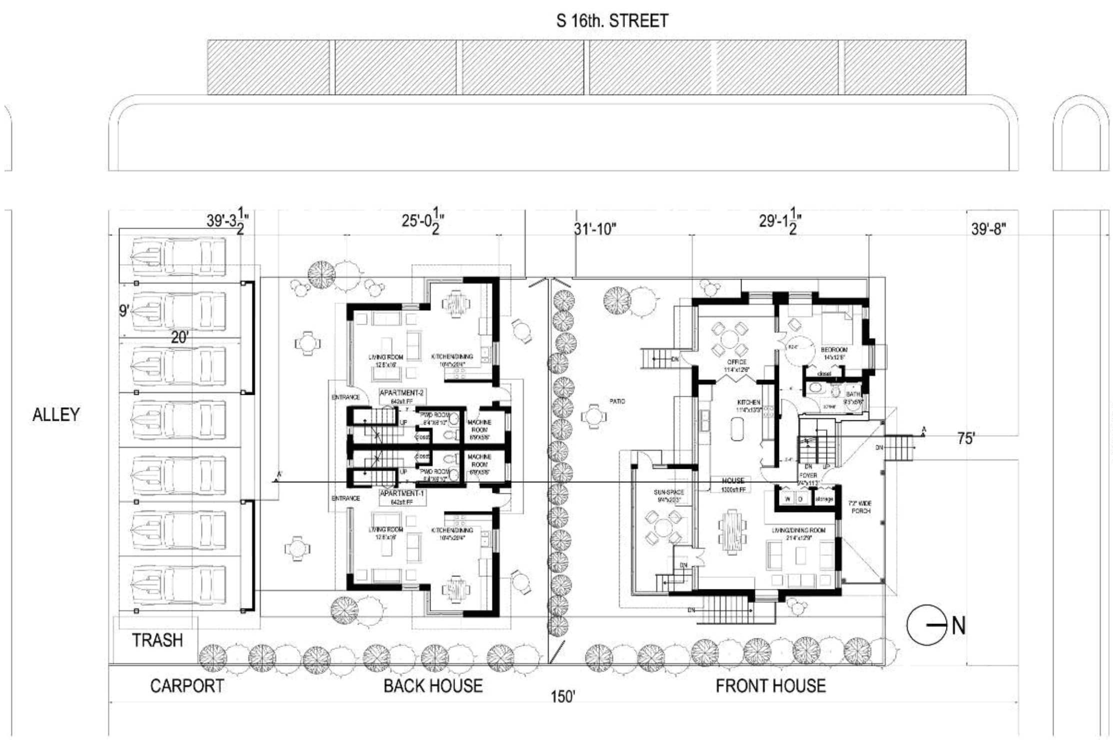


Figure B.38 2d First Floor Plan

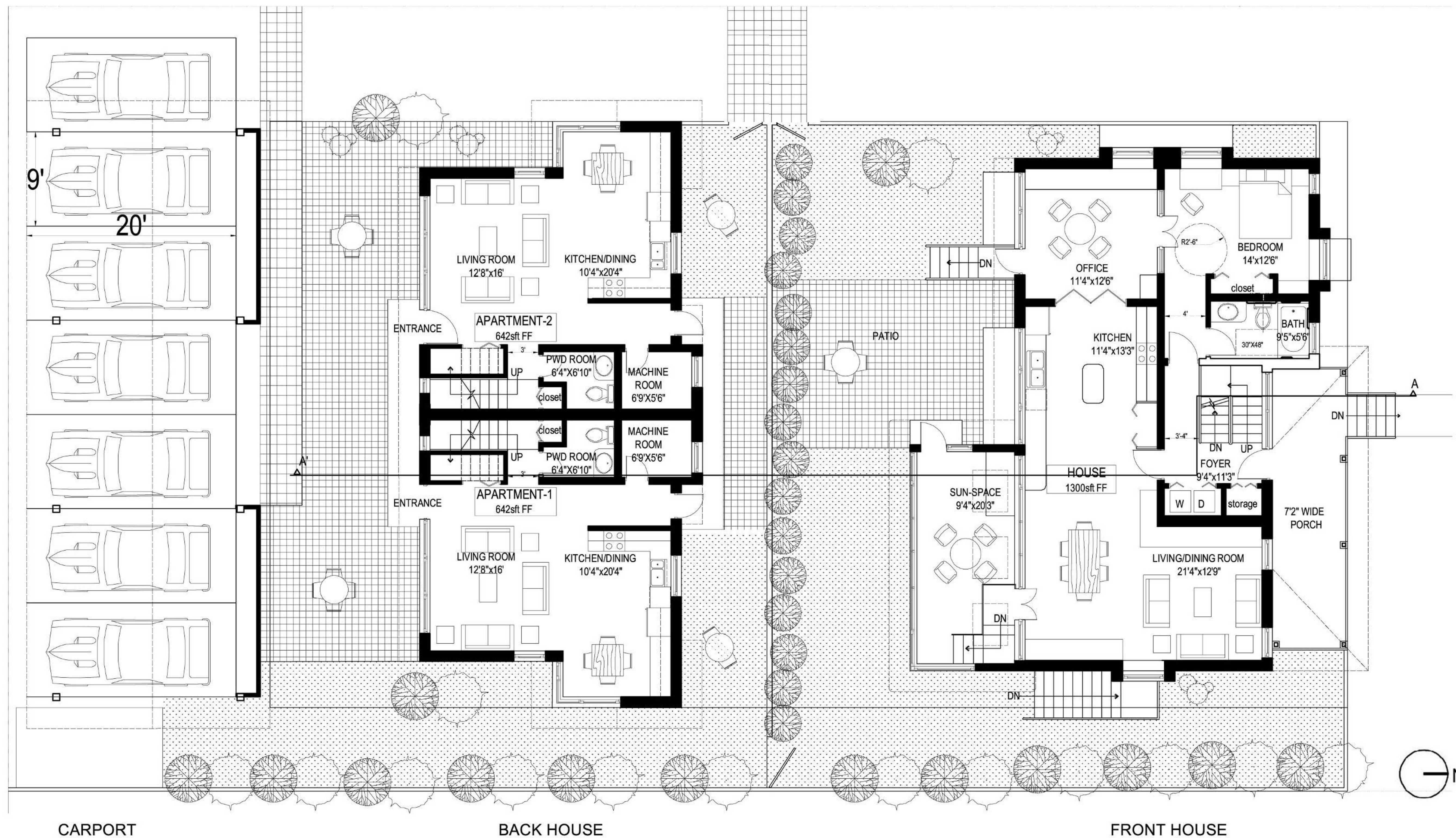


Figure B.39 2d Second Floor Plan

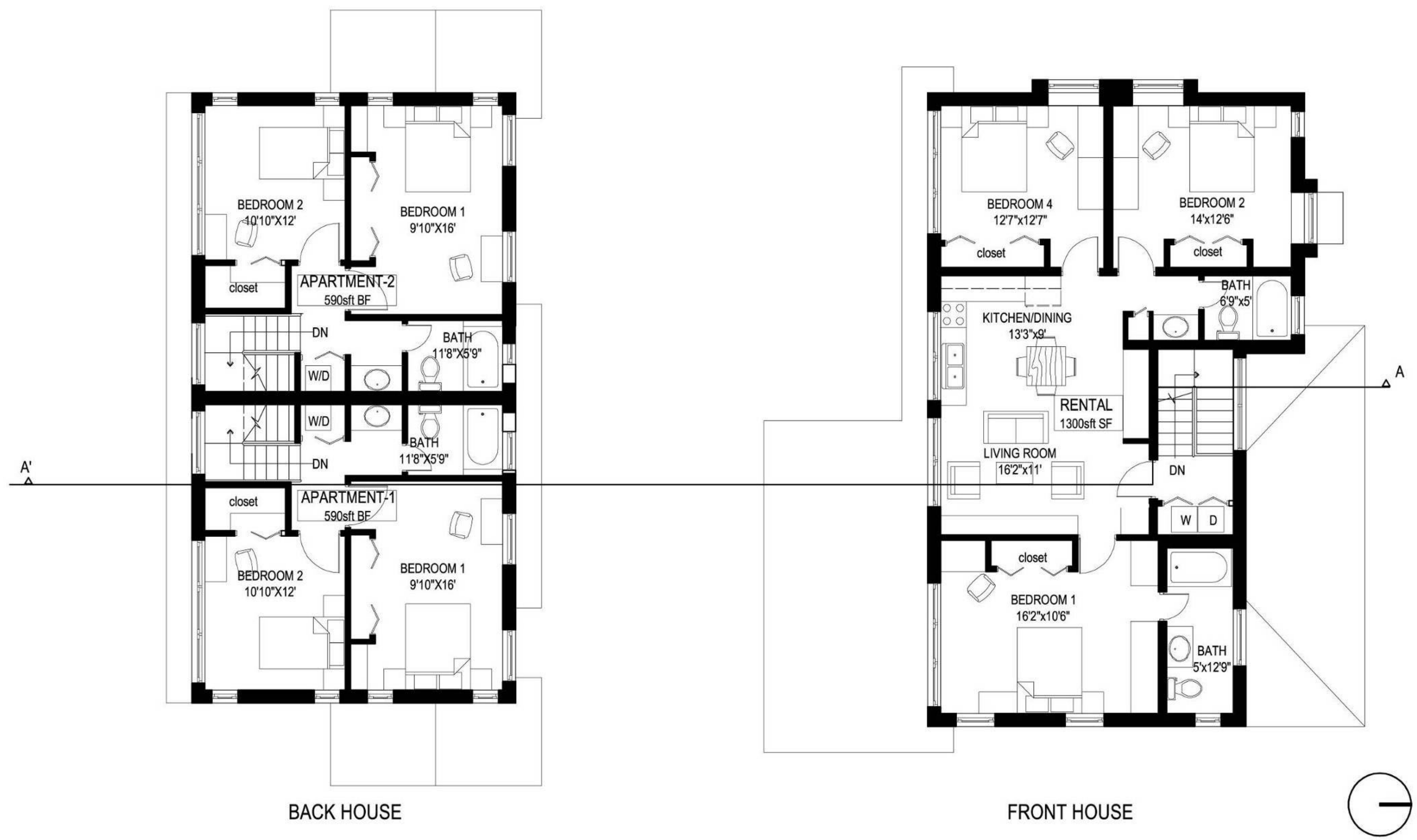


Figure B.40 2d Basement Floor Plan

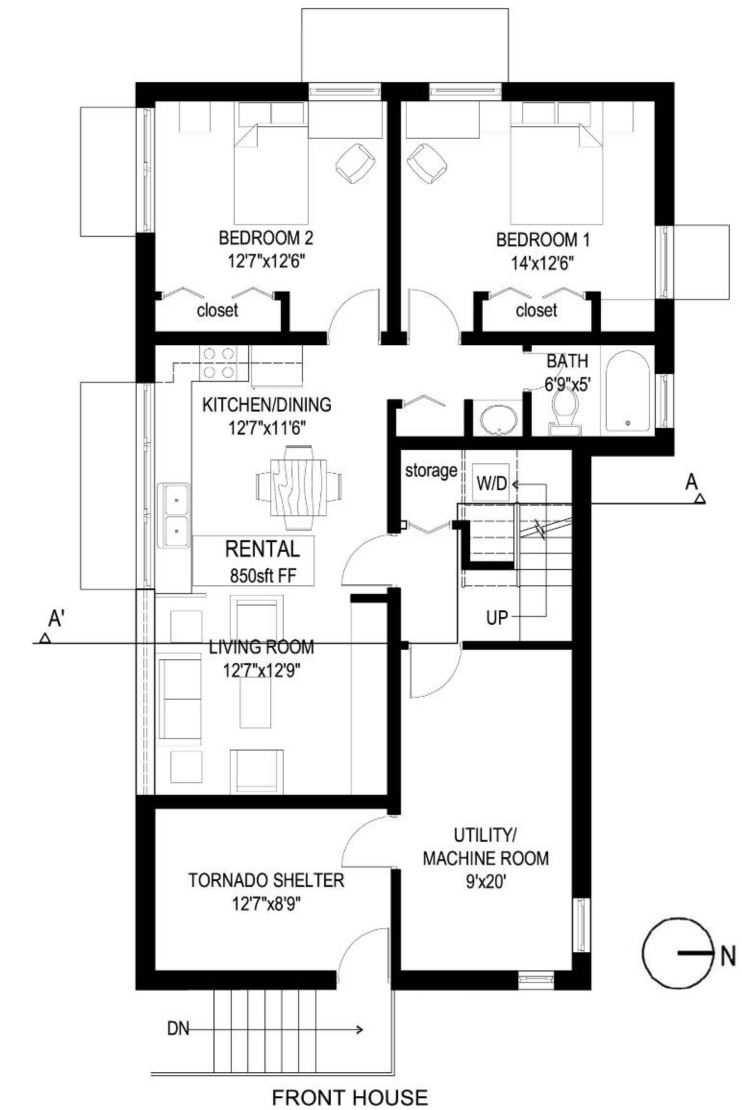


Figure B.41 2d Section AA’

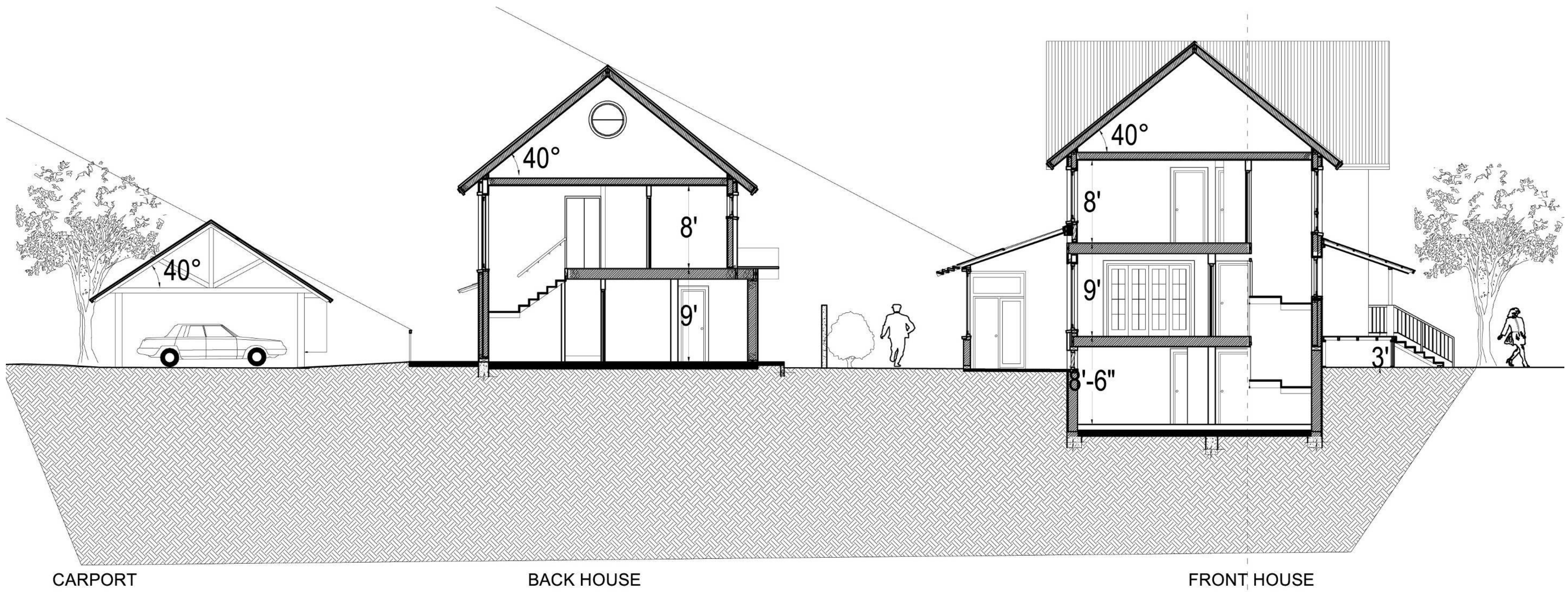


Figure B.42 2d South and North Elevation

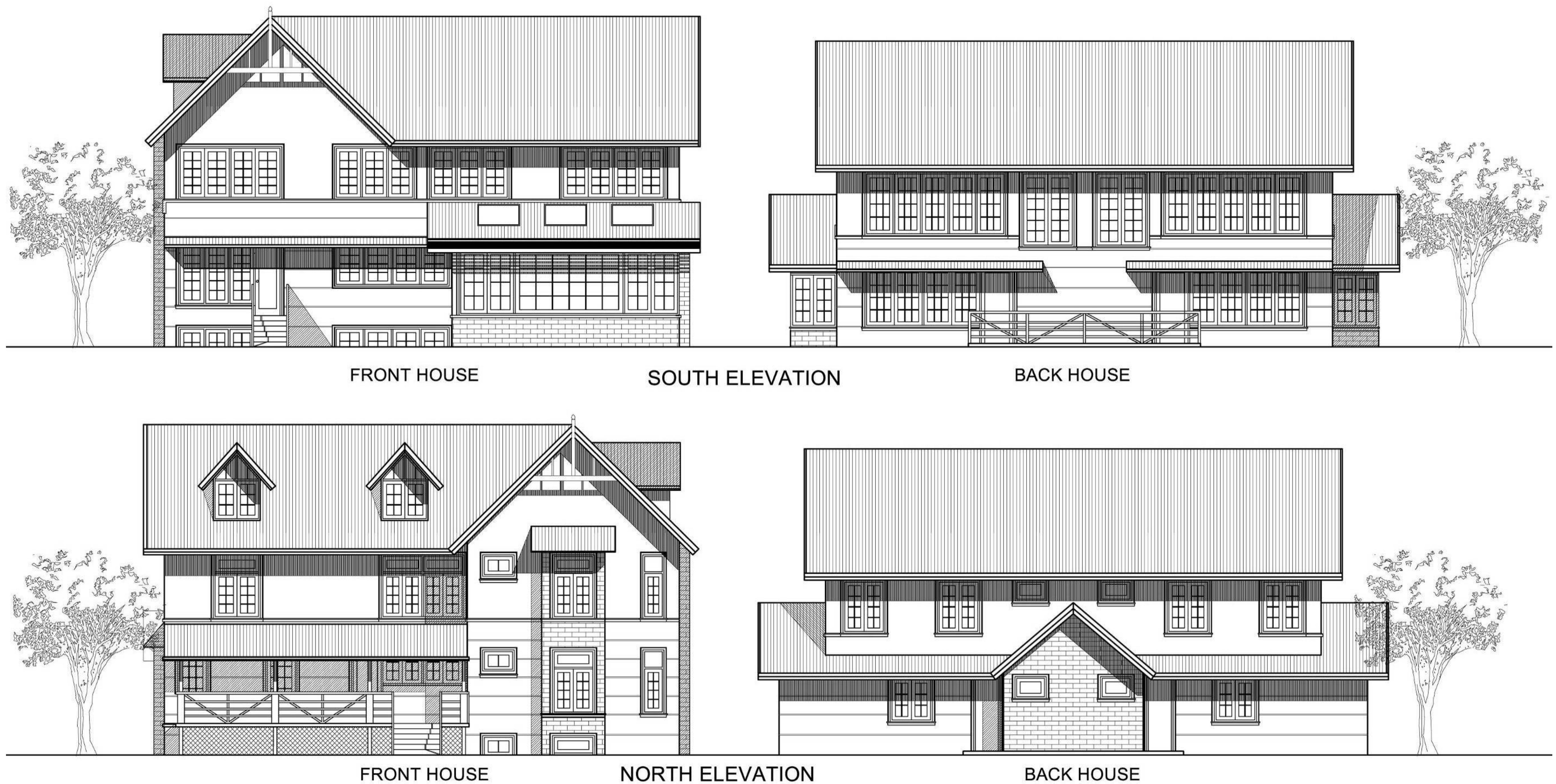
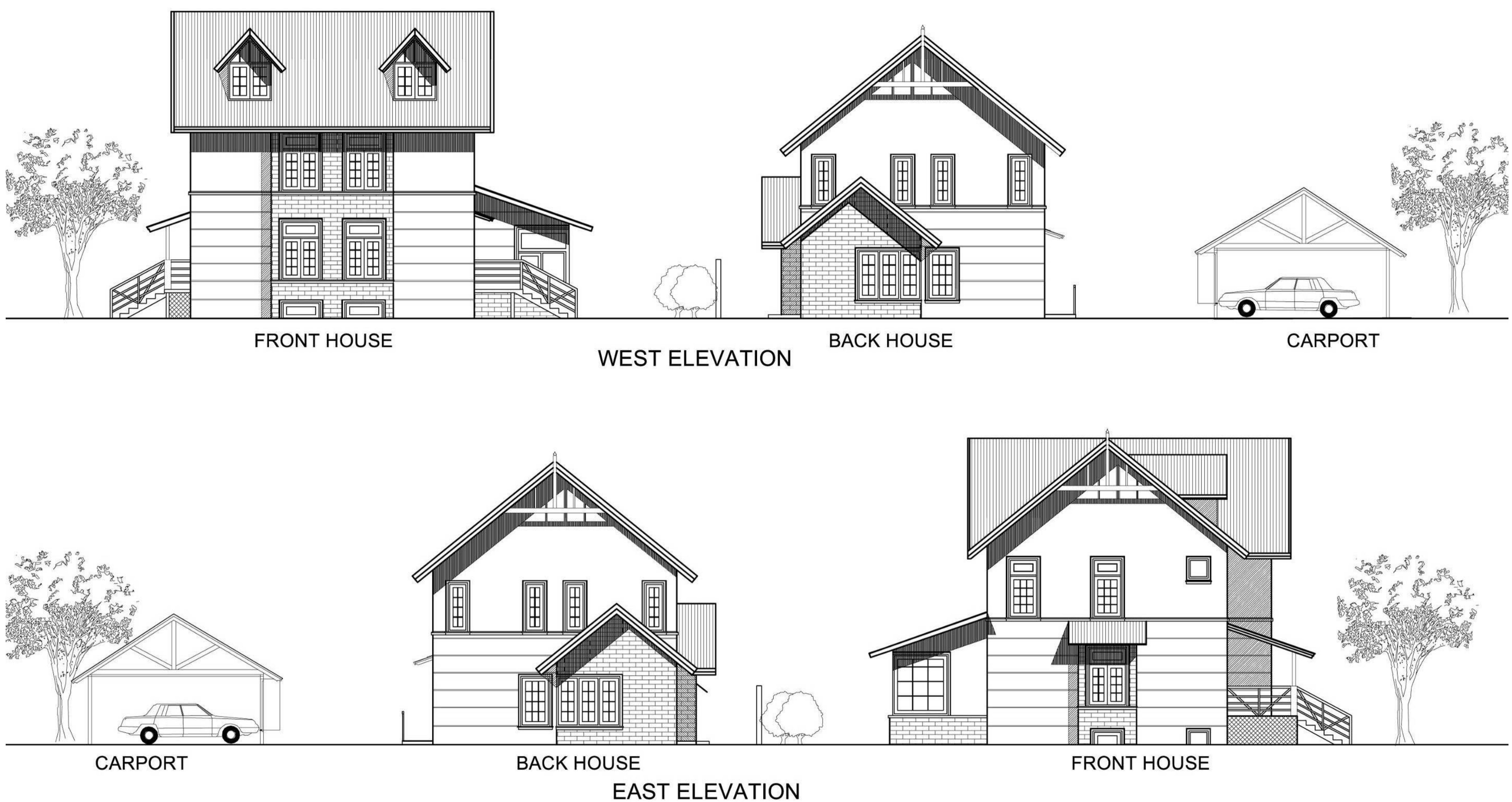


Figure B.43 2d East and West Elevation



Type 3a House

The house in Type 3a has sun decks in the front and back house and the back house is shorter as it has a basement floor. The floor area of each apartment in the back house is 1,230 sf. The studio apartment in the front house is 500 sf. with a 1,100 sf basement apartment and the rest of the owner occupied portion is 2,100SF.

Figure B.44 3a Location Plan

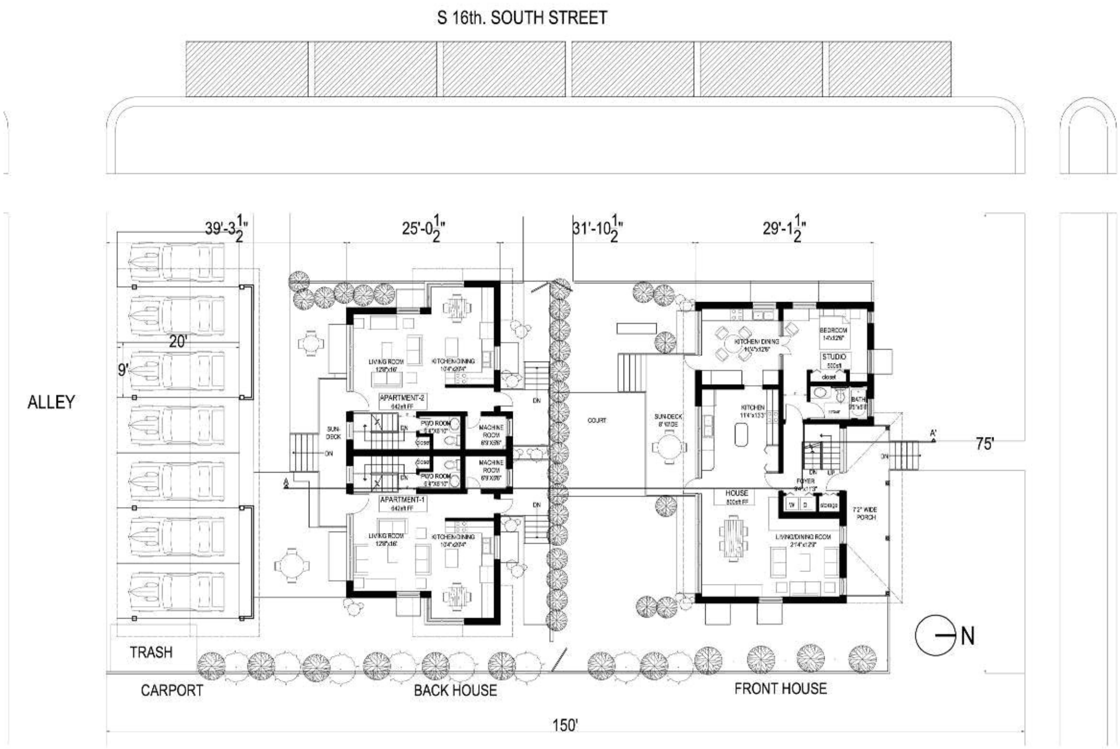


Figure B.45 3a First Floor Plan

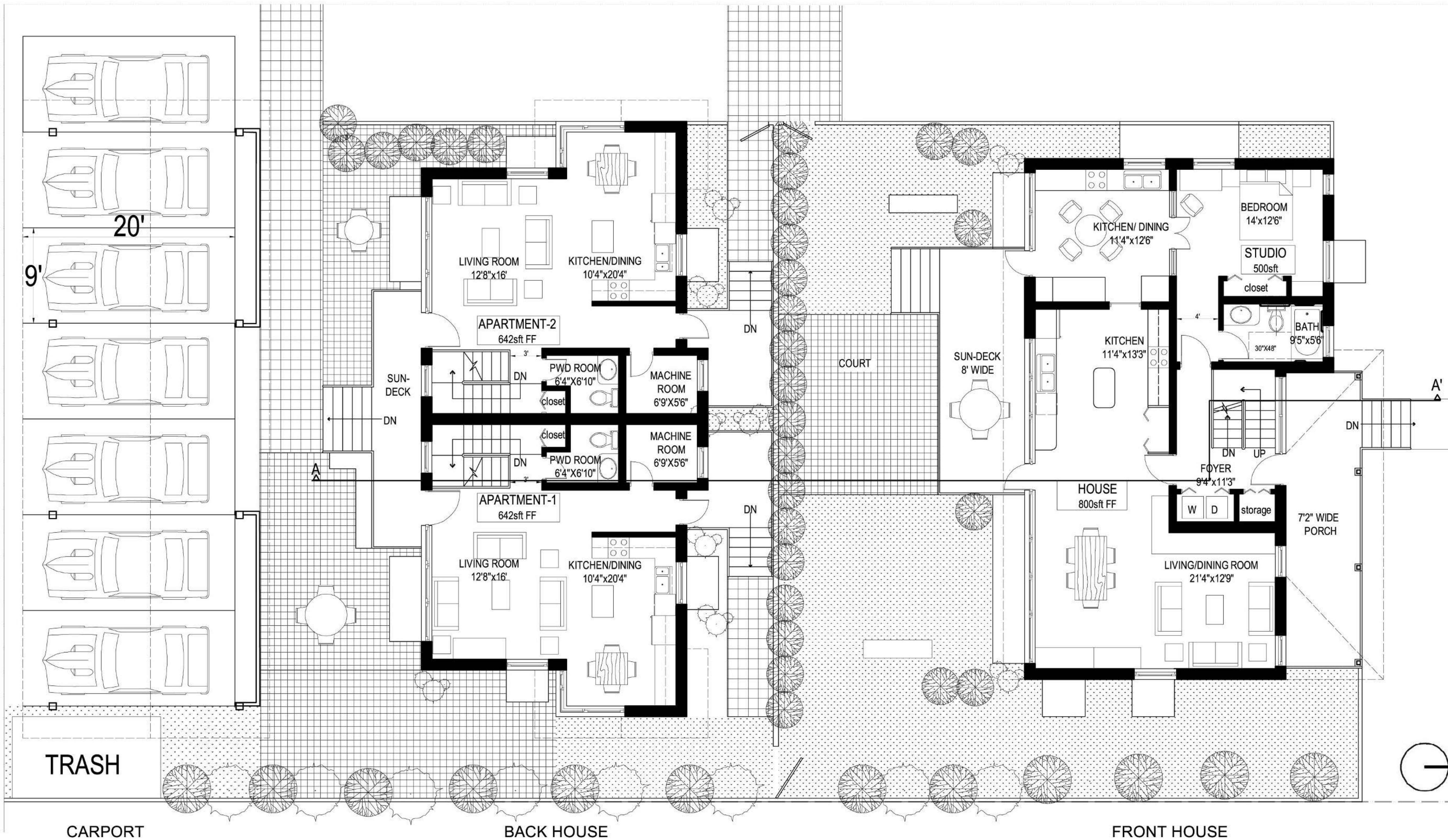


Figure B.46 3a Second Floor Plan

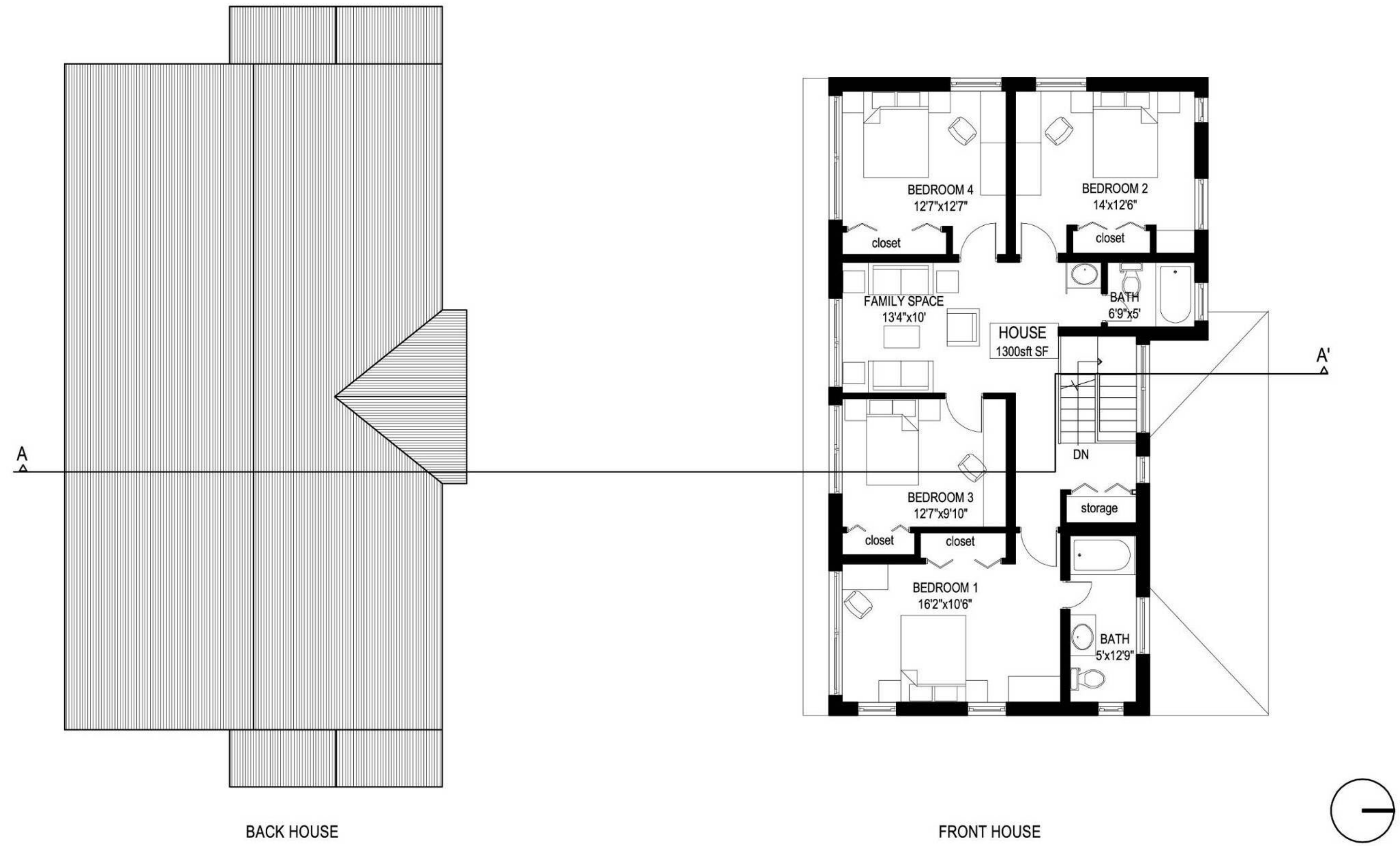


Figure B.47 3a Basement Floor Plan

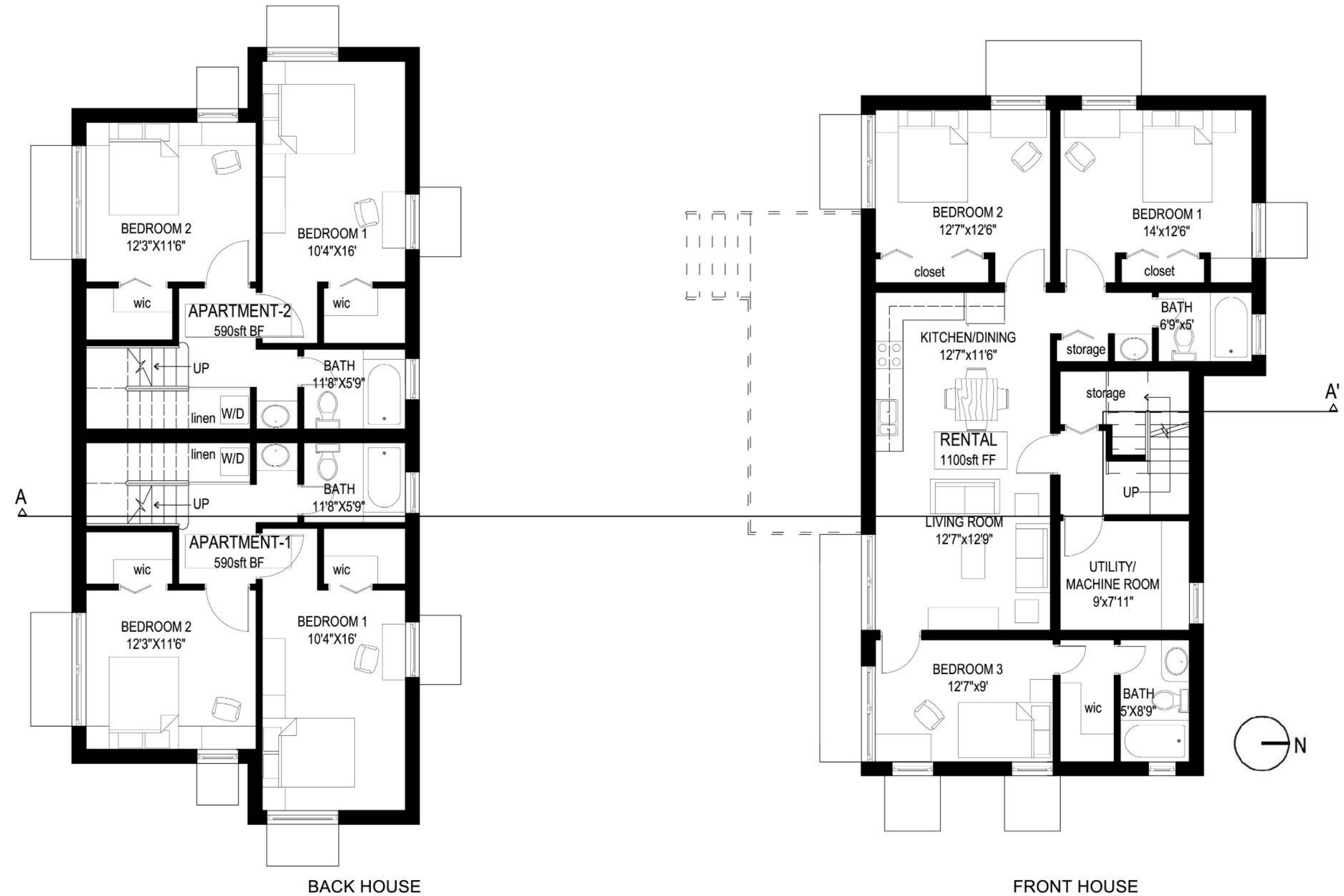


Figure B.48 3a Section AA'

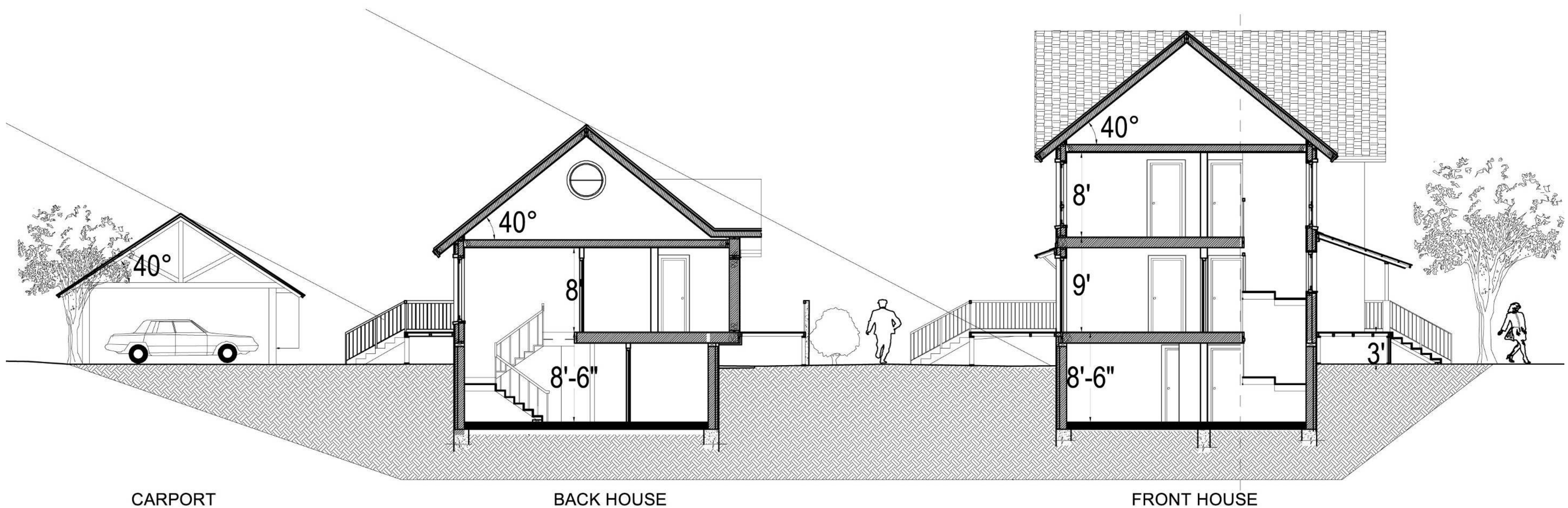


Figure B.49 3a South and North Elevation

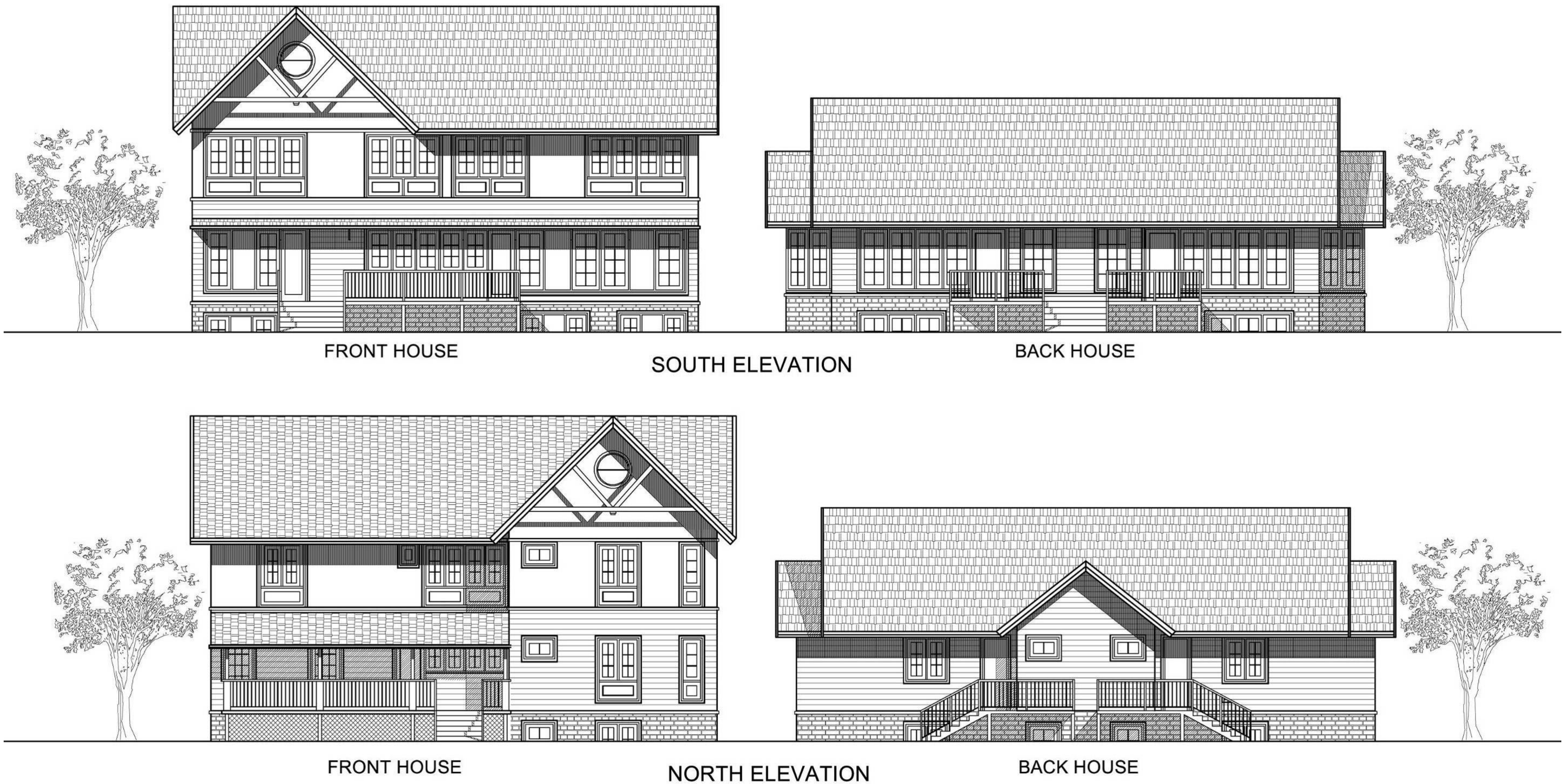
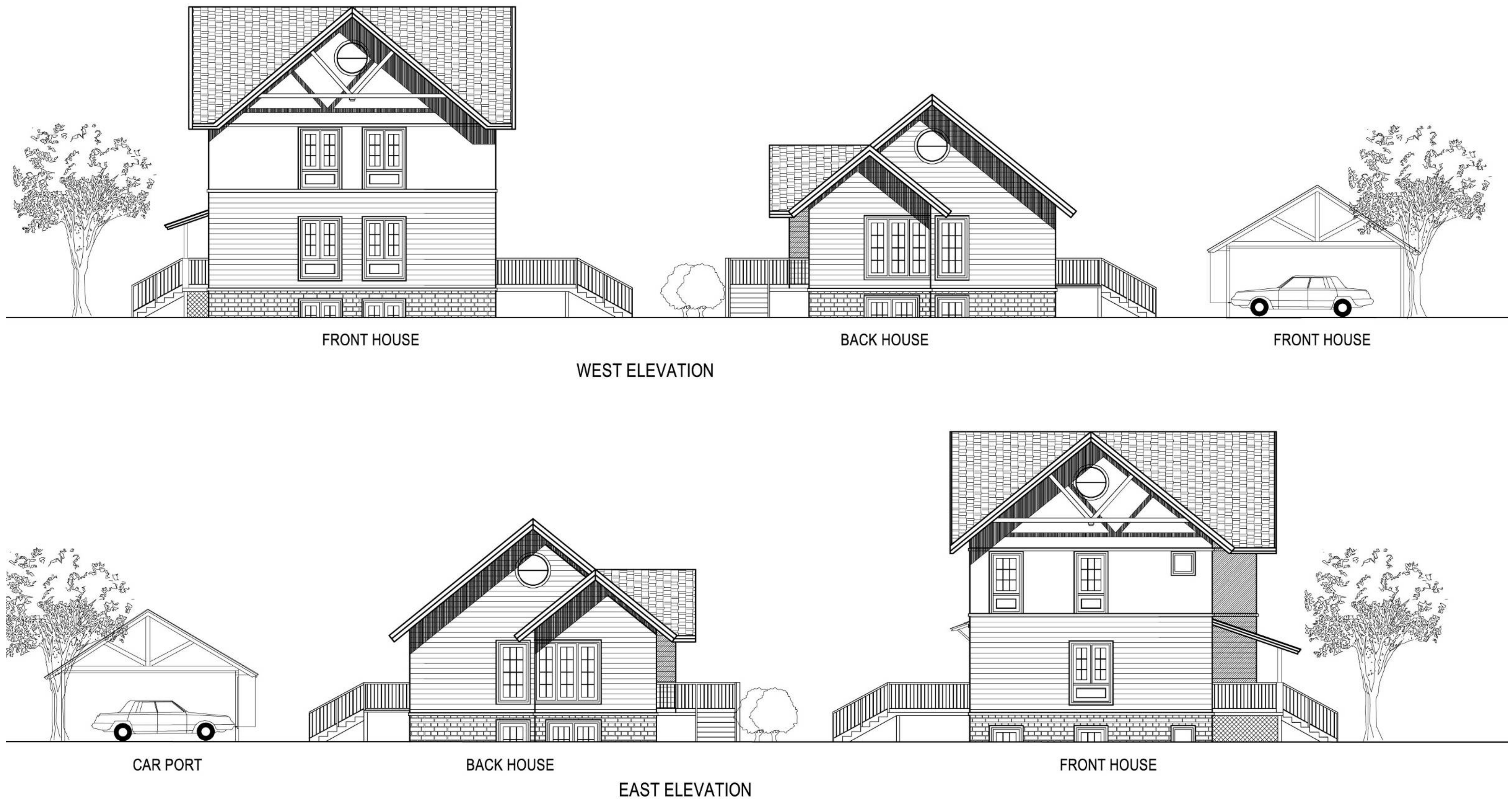


Figure B.50 3a West and East Elevations



Type 3c House

The design has longer sun space (408 sf.) in the front house and the back houses have a basement floor and a first floor. The floor area of each apartment in the back house is 1,230 sf. The studio apartment in the front house is 500 sf. with a 1,100 basement apartment and the rest of the owner occupied portion is 2,400SF.

Figure B.51 3c Location Plan

Figure B.52 3c First Floor Plan

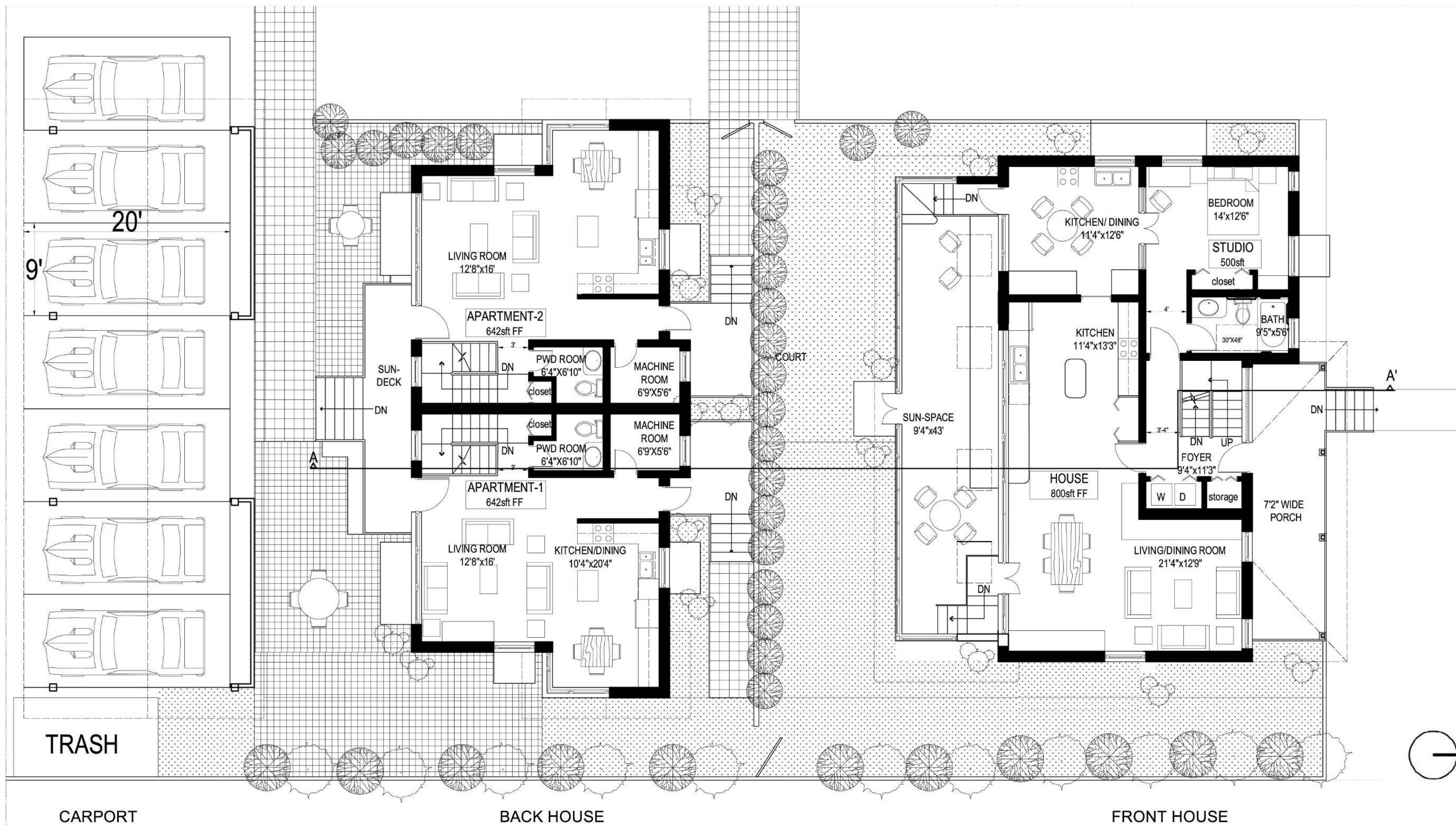


Figure B.53 3c Second Floor Plan

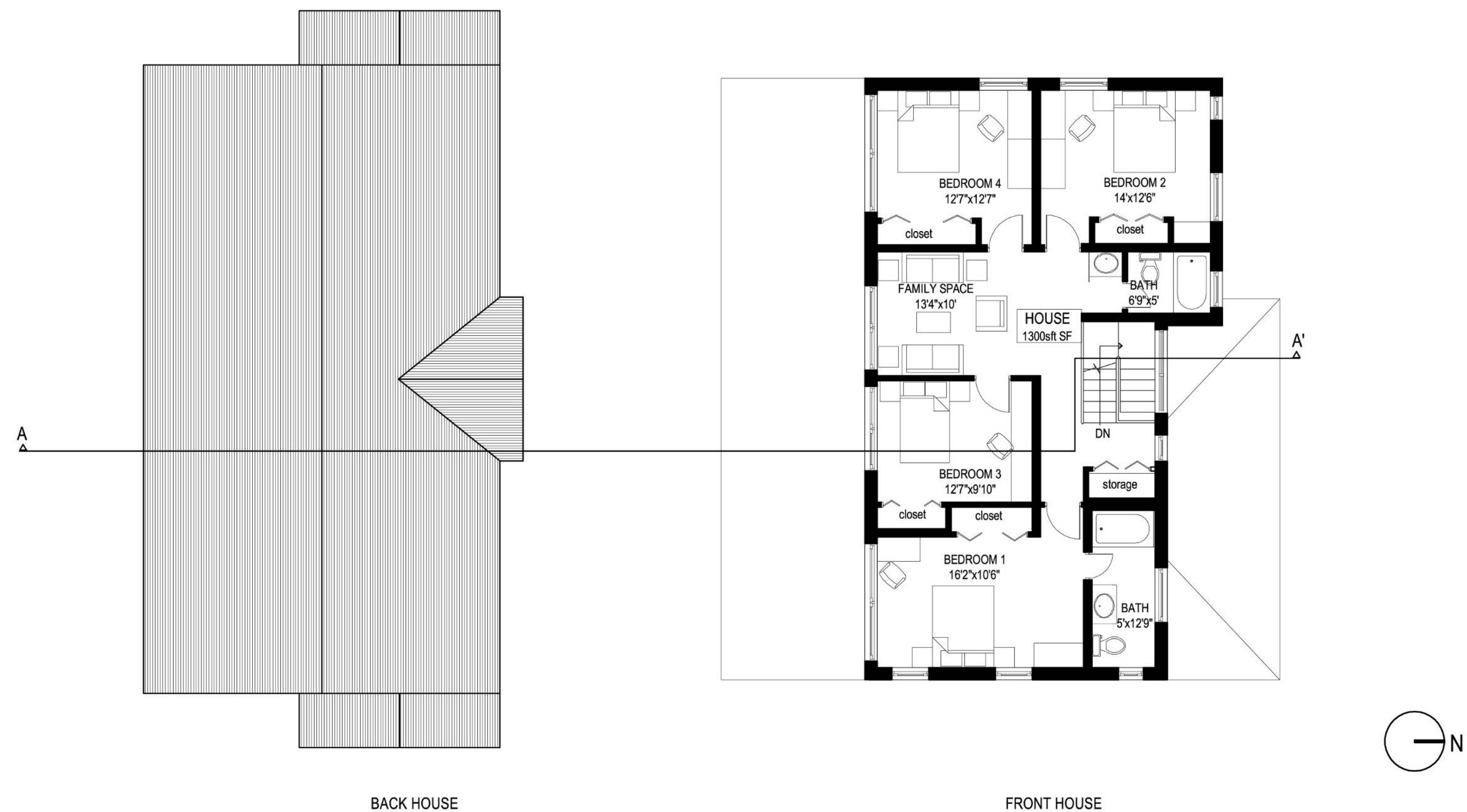


Figure B.54 3c Basement Floor Plan

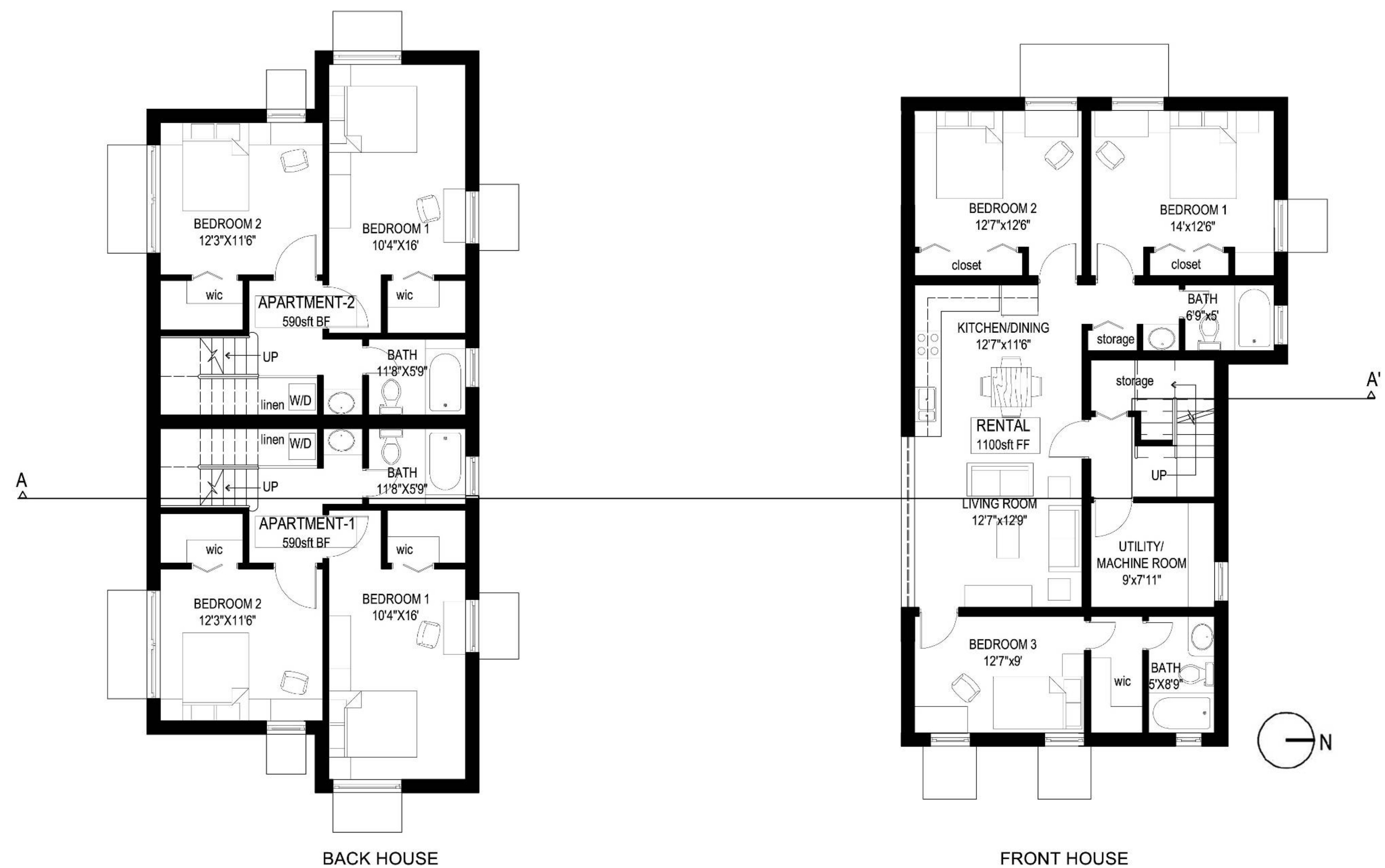


Figure B.55 3c Section AA’

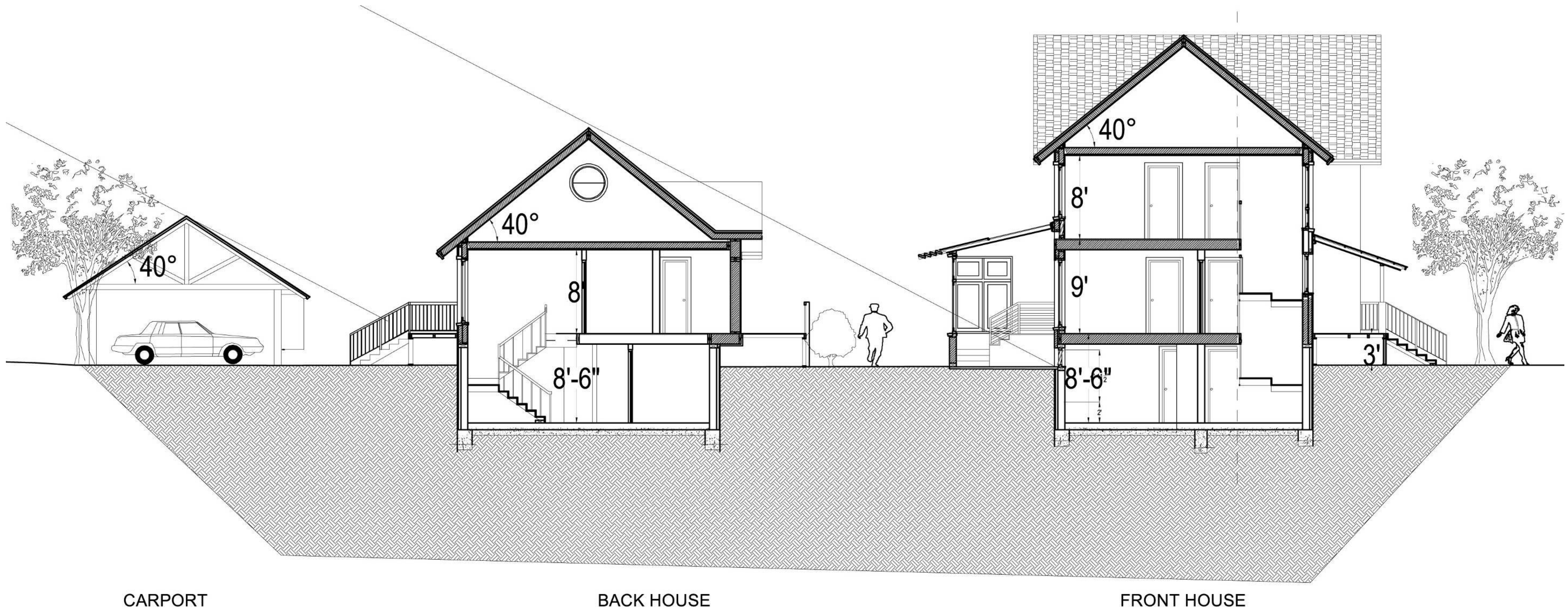
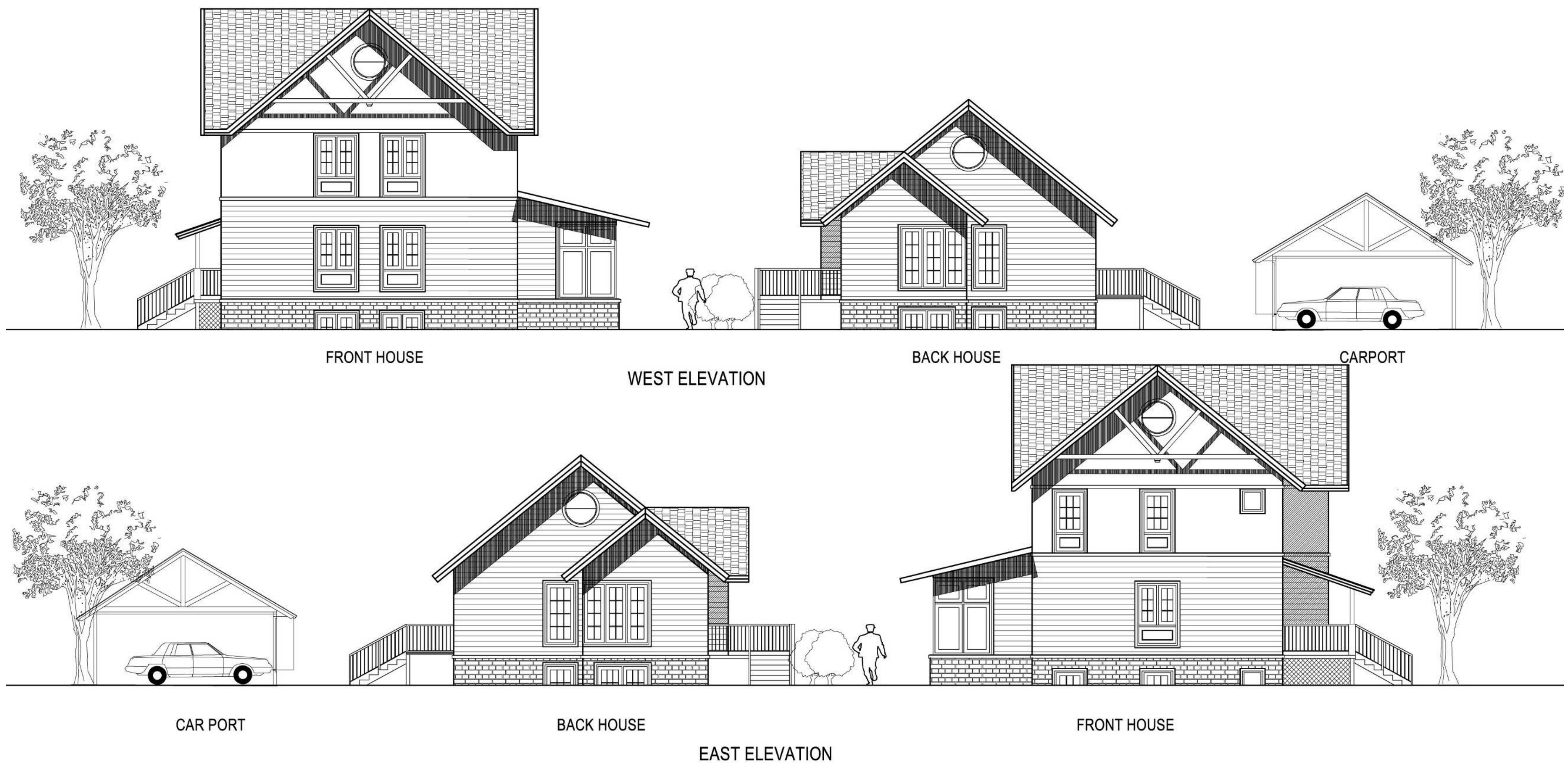


Figure B.56 3c South and North Elevations

Figure B.57 3c West and East Elevations



Type 3d House

The design has sun decks in the front house and the back houses. The back house is a two storied structure with each apartment having an area of 1,230 sf. The studio apartment in the front house is 500 sf. with an 1,100 basement apartment and the rest of the owner occupied portion is 2,100SF.

Figure B.58 3d Location Plan

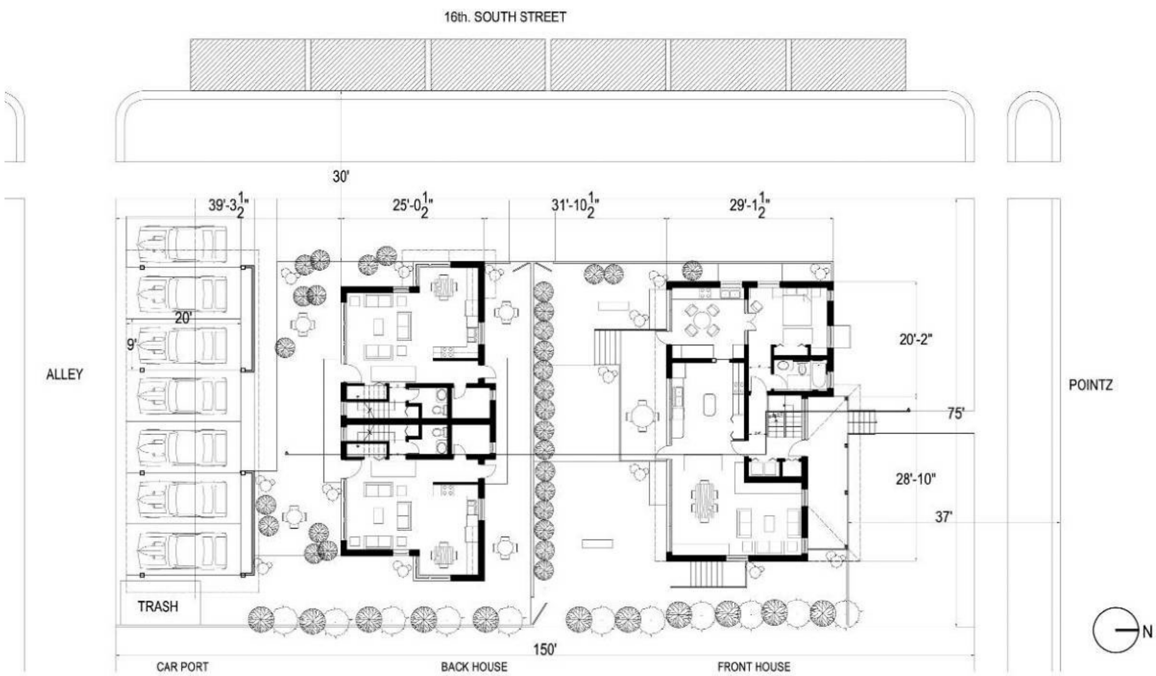


Figure B.59 3d First Floor Plan

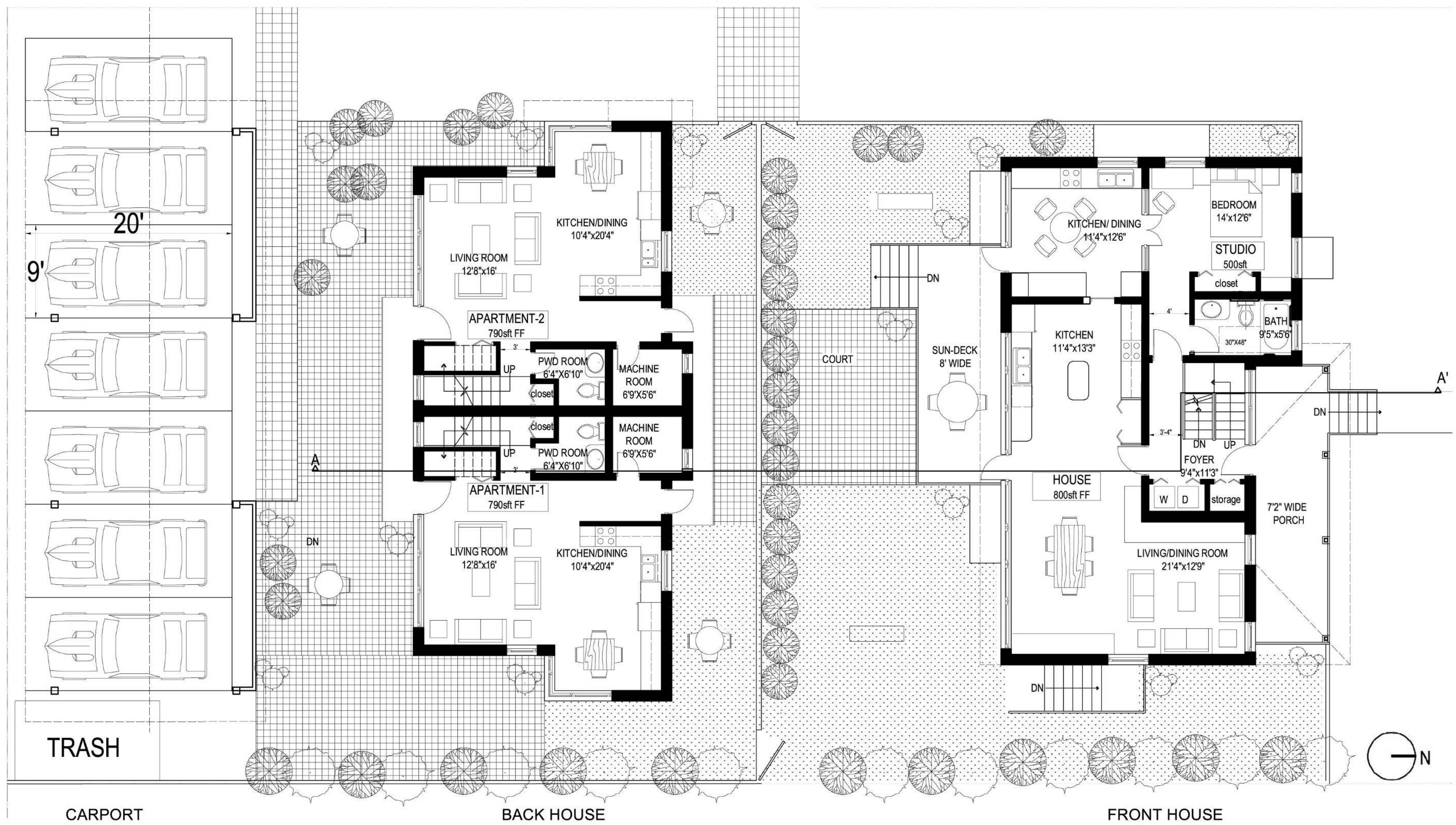


Figure B.60 3d Second Floor Plan

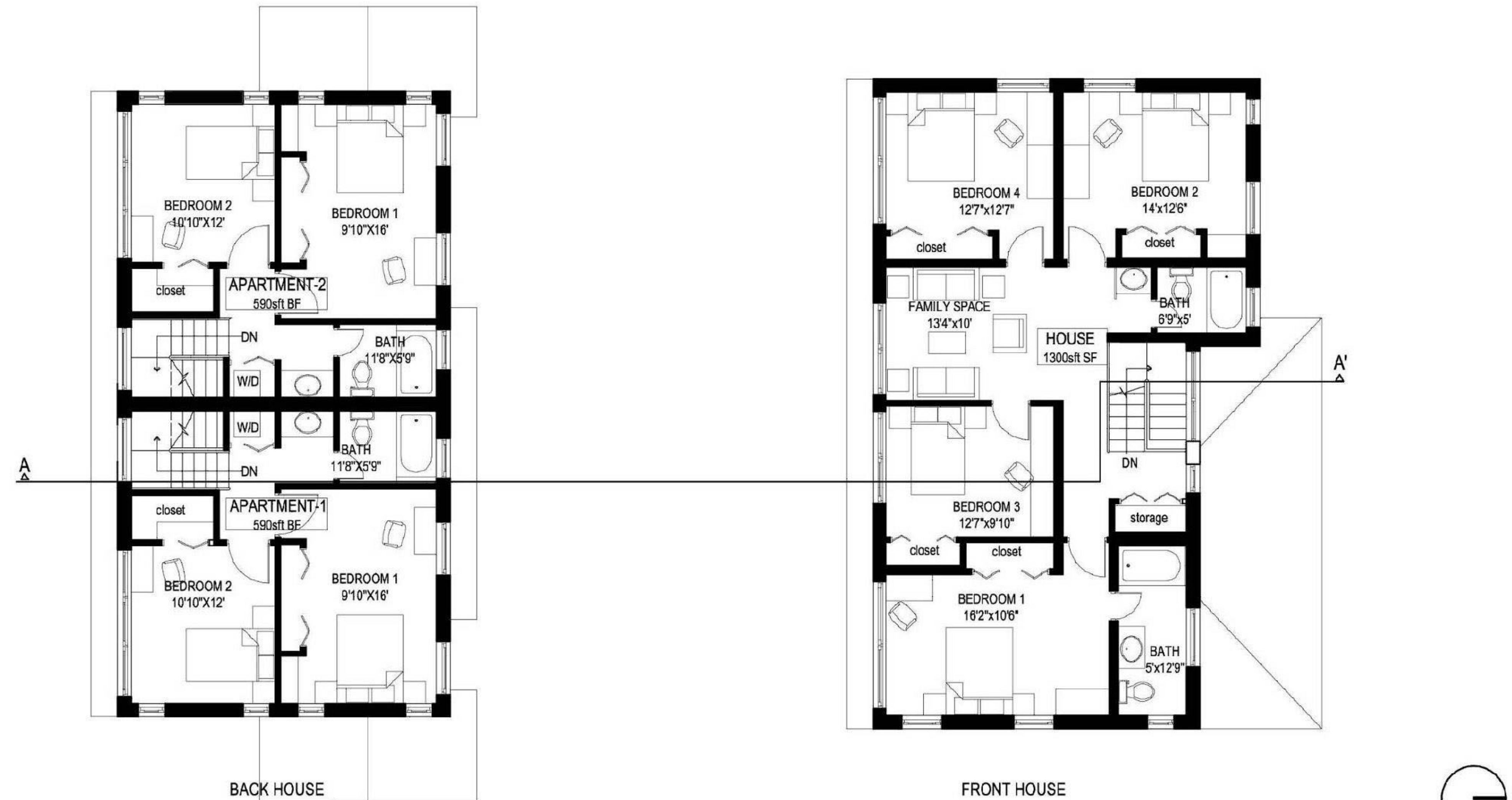


Figure B.61 3d Basement Floor Plan

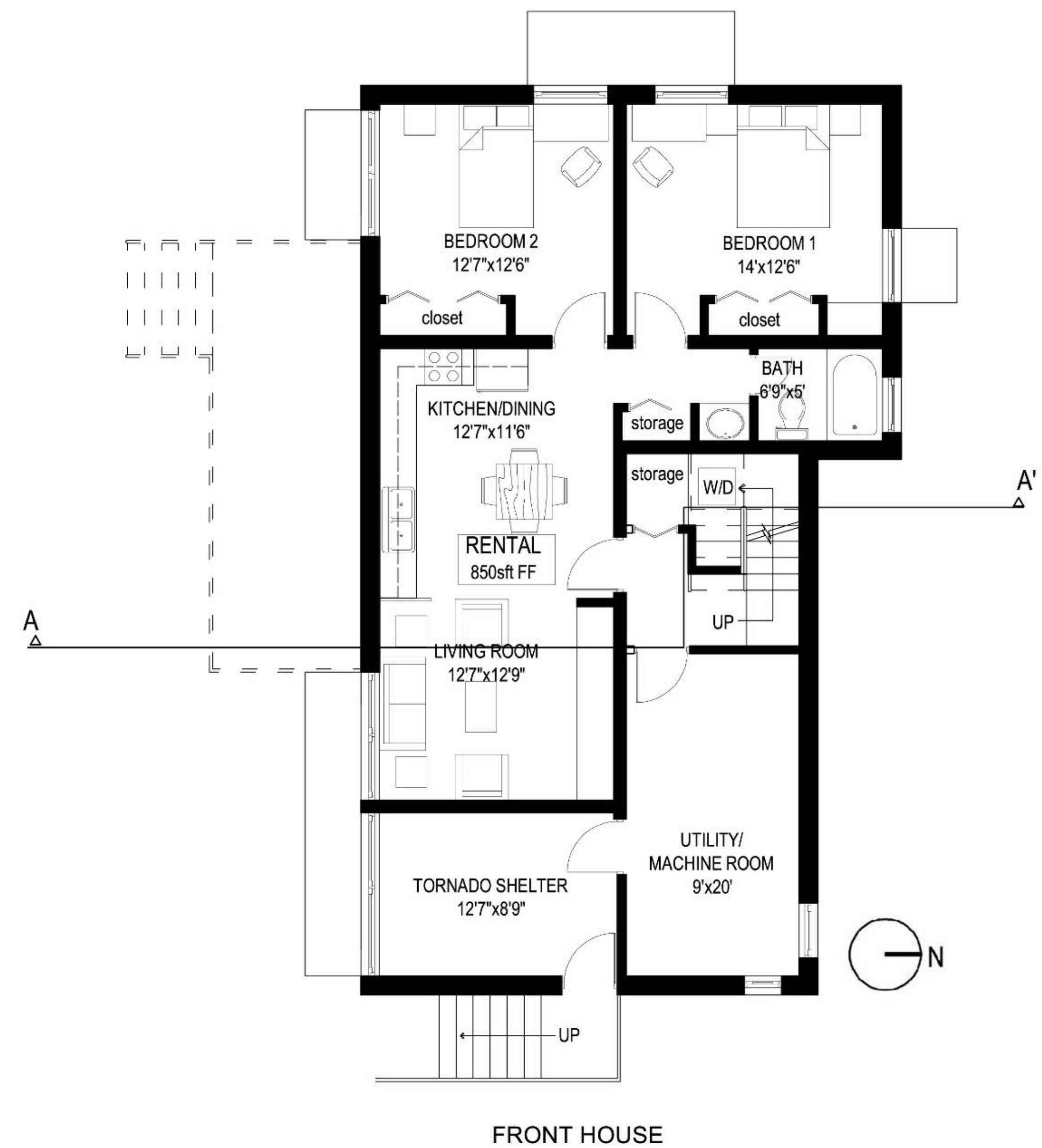


Figure B.62 3d Section AA'

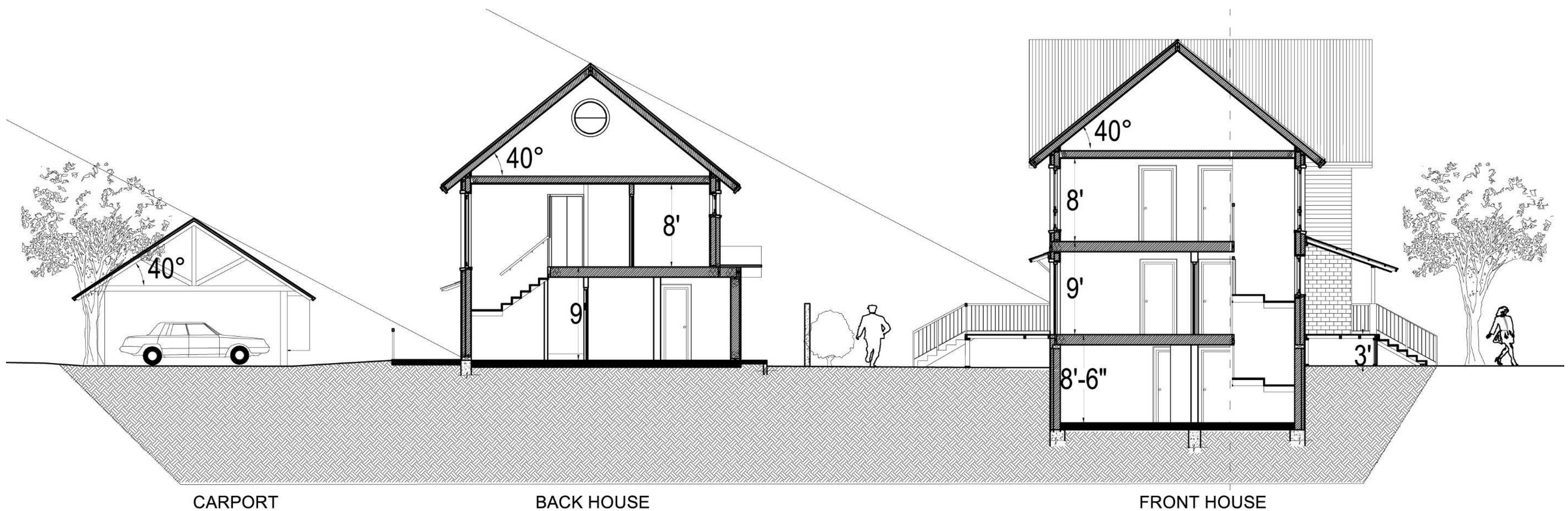
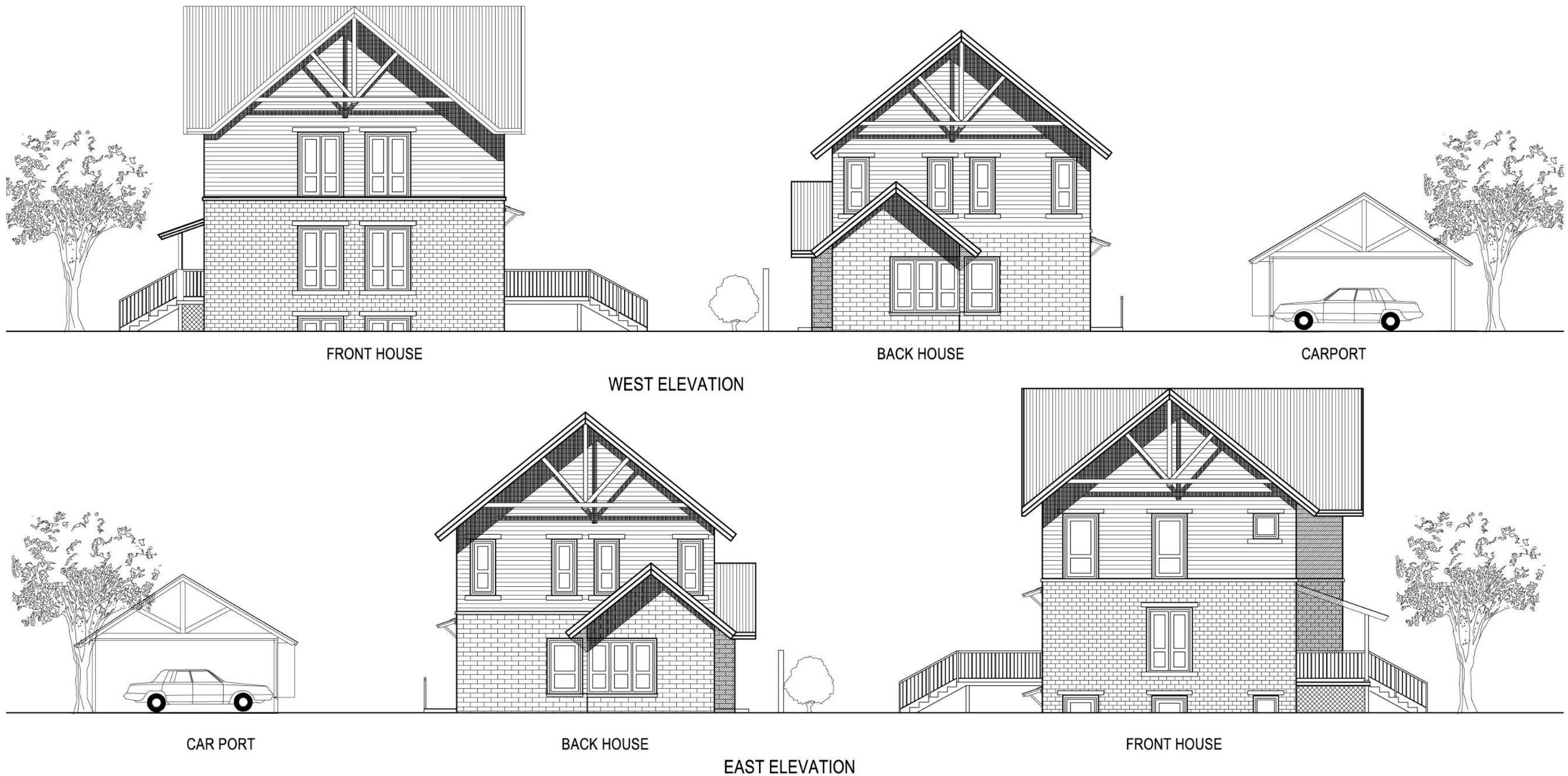


Figure B.63 3d North and South Elevations

Figure B.64 3d West and East Elevations



Appendix C - Energy Analysis

Front House: Heat Gain Calculation

A) Heat Gain through windows

i) Externally shaded windows: $\frac{Window\,area}{Floor\ area}\times 16 = \frac{558}{3900}\times 16 = 2.28$

ii) Externally unshaded windows: $\frac{Window\,area}{Floor\ area}\times 16\times 4 = \frac{143}{3900}\times 16\times 4 = 2.35$

B) Heat Gain through walls

i) (Conventional wall area/ floor area) X U-valueX15 (Constant for site's outdoor design temperature) $= \frac{2538}{3900}\times 0.04\times 15 = 0.39$

ii)(Earth contact wall area/ floor area) X U-valueX15 (Constant for site's outdoor design temperature) $= \frac{938}{3900}\times 0.02\times 15 = 0.072$

C) Heat Gain through roofs

(Roof area/ floor area) X U-value X 35 (Constant for site's outdoor design temperature)

$$= \frac{1928}{3900}\times 0.02\times 35 = 0.346$$

D) Heat Gain through infiltration

Infiltration load X 16 (Constant for site's outdoor design temperature) = 0.09 X 16= 1.44

Total Heat Gain = A (i + ii) + B (i +ii) + C + D

= 2.2 + 2.35 + 0.39+ 0.072+ 0.346+ 1.44

= 6.878 Btu/hr,sf.

6.878 Btu/hr,sf.= 3.152 X 6.878 watts/m^2

=21.67 Watts/ m^2

=21.67 X 0.09 Watts/ sf.

Total Heat Gain = 1.95 Watts/ sf.

Back House Passive Heating and Cooling Results

Following the steps described in the workbook by Gary J. Coates, the various calculations were carried out.

Table C.1 Size of Solar Aperture on the South (each apartment)

1	Total Conditioned Floor:	1,230 sf	
2	**Total Solar Aperture :**	**233.7**	
3	Ratio of Solar Aperture/Floor Area :	0.19	
4	Estimated SSF (No Night Time Insulation) :	21(low)	33 (high)
5	Estimated SSF (Night Time Insulation) :	41(low)	65(high)

Thus if there is a solar collection area of 19% of the total floor area then the total solar savings fraction in heating the house is 21-33% if no night time insulation is used and 41-65% when night time insulation is used. (Brown and DeKay, 2001,p 249)

Table C.2 Direct Gain and Thermal Mass Area

	Area(sft)	% of Solar Aperture
Direct Gain (windows)	**140**	**60%**
Thermal Mass(floors)	**94**	**40%**
Total	**234**	**100**

The calculations suggested that the total area of the windows on the south façade be 140 sf with a total thermal mass of 94 sf. The total area of windows finally provided after the final simulations was 131 sf which is nearly equal to that suggested by the calculations in Table C.1 and C.2. Thermal mass was achieved by providing clay tiles in the floor of the living room.

The recommended R-values for the various building components are provided in Table C.3. (Brown and DeKay, 2001,p 214,p 272)

Table C.3 Recommended 'R' and 'U' values for the building components

	Opaque Walls	Earth Contact Walls	Roofs	Windows
R-Value	23	43	49	3.1
U-Value (1/R)	0.04	0.023	0.2	0.33
Thickness	6"	-	16"	

Heat Gain was calculated in the following way as described by Tables C.4, C.5 and C.6 and Figure C.65 below:

Table C.4 Relation between area of opaque, insulated building envelope and total glazing (non-south) area

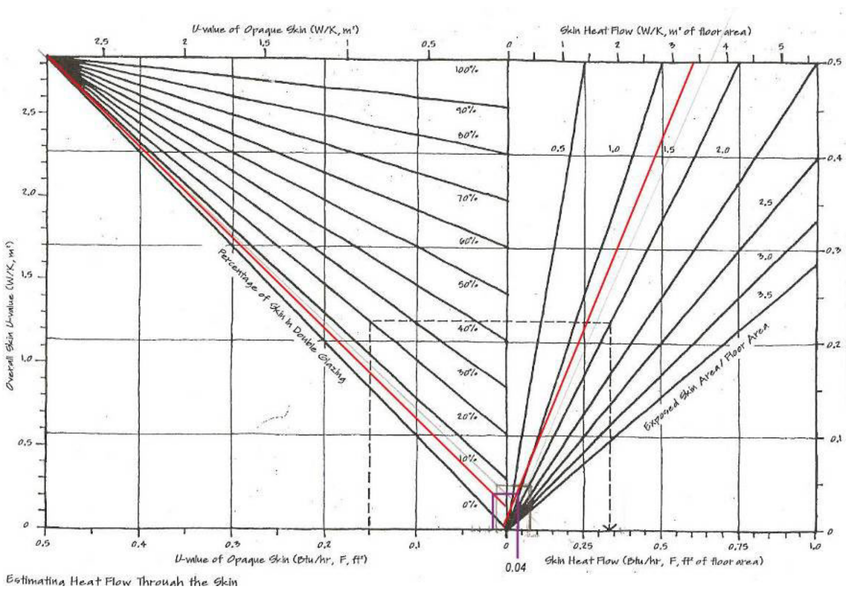
a	Total Area of (opaque and glazed) building envelope (exclusive of South wall)	3,200
b	Total Area of glazing exclusive of South Wall	158sf
c	% of Total Envelope (exclusive if South Wall) in glazing (b/a)	5.00%
d	Total Area od opaque building envelope exclusive if south wall (a-b)	3,042
e	% of Total Envelope in opaque Building Envelope (d/a)	95.00%

Table C.5 Area of Weighted Average U-Value of Opaque Skin

	Area (A in sf.)	% of Total Opaque (A/d from table 4)	R-value	U-Value (1/R)	%XU
Opaque Roof	1,800	0.6	49	0.02	0.012
Earth Contact Wall (basement)	972	0.3	43	0.02	0.006
Opaque Wall	2086	0.7	23	0.04	0.027
Area Weighted Avrage U-Value of the Opaque Skin					0.015

Figure C.65 Skin Heat Flow Graph

(Coates 2007, p 2-24)



Finally a compilation of the calculation above was done to arrive at the total heat loss of the building. This has been depicted in Table C.6.

Table C.6 Building Heat Loss Calculation

a	Percentage of (non-South) Exposed Skin in Double-Glazing (Answer c in Table 4)	5.00%
b	Exposed Skin Area/Floor Area (Answer a in Table 4/floor area)	1.3
c	**Skin Heat Flow (Btu/hr,F,sf. of floor area)(from fig.1)**	**0.004**
d	**Infiltration Heat Loss (Btu/hr,F,sf. of floor area)**	**0.09**

Thus the Heat Loss can be calculated as:

Skin Heat Flow (from Table 6) + Infiltration (from Table 6) = 0.094 Btu/hr,F,sf.floor area

The Total Heat Loss = 0.094 X 24 hrs/day= 2.256 Maximum Heat Loss (Btu/DD,sf.)

The Total Heat Loss of the building is less than 5.6 Btu/DD,sf. , the maximum allowed heat loss for a passively soar heated building (exclusive of south wall) in a region with annual degree days between 3000-5000. (Coates, G, 2007, p 2-22)

Similarly the heat gained through the envelope was calculated as follows (Brown 2001, p 62):

A) Heat Gain through windows

i) Externally shaded windows: (Window area/floor area) X 16

= (402/2460) X16 = 2.61

ii) Externally unshaded windows: (Window area/floor area) X 16X 4

= (88/2460) X 16 X4 = 2.28

B) Heat Gain through walls

i) (Conventional wall area/ floor area) X U-valueX15 (Constant for site’s outdoor design temperature)

= (2096/2460) X 0.04 X 15 = 0.51

ii)(Earth contact wall area/ floor area) X U-valueX15 (Constant for site’s outdoor design temperature)

= (972/2460) X 0.02 X 15= 0.118

C) Heat Gain through roofs

(Roof area/ floor area) X U-value X 35 (Constant for site’s outdoor design temperature)

= (1800/2460) X 0.02 X 35= 0.512

D) Heat Gain through infiltration

Infiltration load X 16 (Constant for site's outdoor design temperature) = 0.09 X 16= 1.44

Total Heat Gain = A (i + ii) + B (i +ii) + C + D

= 2.61 + 2.28 + 0.51+ 0.118+ 0.512+ 1.44

= 7.47 Btu/hr,sf

7.47 Btu/hr,sf= 3.152 X 7.47 watts/m^2

=23.54 Watts/ m^2

=23.54 X 0.09 Watts/ sf

Total Heat Gain = 2.11 Watts/ sf

Energy 10 Simulation for Front House

Table C.7 summarizes the description of the two buildings, the reference as well as the low energy case. It gives the specification of the materials used for construction as well as the R- values achieved. Shading devices have been provided in the low-energy case, the design of which has been described later in this document. One inference from this analysis was that shading devices in the West, South and East windows reduced the energy used in cooling as the shades obstructed the high summer sun.

Table C.7 Energy-10 Building Construction Summary

Description:	Reference Case	Low-Energy Case
Scheme Number:	1 / Not Saved	2 / Not Saved
Library Name:	ASHRAELIB	ASHRAELIB
Simulation status, Thermal/DL	valid/NA	valid/NA
Weather file:	TOPEKA.ET1	TOPEKA.ET1
Floor Area, ft^2	3900	3900
Surface Area, ft^2	8636	8636
Volume, ft^3	32500	32500
Total Conduction UA, Btu/h-F	1281.7	503.6
Average U-value, Btu/hr-ft^2-F	0.148	0.058
Wall Construction	2 x 6 frame, R=17.7,etc	2 x 6 frame poly, R=23.1,etc
Roof Construction	attic, r-30, R=29.4	attic, r-60, R=60.2,etc
Floor type, insulation	Slab on Grade, Reff=9.3,etc	Basement, Reff=41.7,etc
Window Construction	4060 double, wood, U=0.47	4060 low-e al/b, U=0.31
Window Shading	None	40 deg latitude,etc
Wall total gross area, ft^2	3436	3436
Roof total gross area, ft^2	2600	2600
Ground total gross area, ft^2	2600	2600
Window total gross area, ft^2	888	816
Windows (N/E/S/W:Roof)	15/7/11/4:0	6/5/17/6:0

Table C.8 provides a description of the HVAC systems used in the two cases and the option of using thermal mass in the house which has been provided in the design. It was concluded after the simulation that the R values of 2”x6” wooden frame construction with polystyrene insulation would be very close to that of 6” SIP wall panels (23.1). Hence, 2”X6” construction was chosen over the more expensive SIP panels.

Table C.8 HVAC System Description

Operating parameters for zone 1		
HVAC system	DX Cooling with Elect Furn	Fixed COP Heat Pump
Rated Output (Heat/SCool/TCool),kBtu/h	123/62/82	57/37/49
Rated Air Flow/MOOA,cfm	2796/0	2332/0
Heating thermostat	70.0 °F, no setback	68.0 °F, setback to 65.0 °F
Cooling thermostat	78.0 °F, no setup	78.0 °F, setup to 83.0 °F
Heat/cool performance	eff=100,EER=8.9	COP=3.5,EER=18.0
Economizer?/type	no/NA	no/NA
Duct leaks/conduction losses, total %	11/10	11/10
Peak Gains; IL,EL,HW,OT; W/ft²	0.20/0.04/0.66/0.36	0.15/0.03/0.66/0.36
Added mass?	none	1300 ft², 8in cmu
Daylighting?	no	yes, continuous dimming
Infiltration, in²	ELA=321.9	ELA=87.1
Operating parameters for zone 2		
HVAC system	DX Cooling with Elect Furn	Fixed COP Heat Pump
Rated Output (Heat/SCool/TCool),kBtu/h	100/44/59	42/24/33
Rated Air Flow/MOOA,cfm	1778/195	1118/195
Heating thermostat	70.0 °F, no setback	68.0 °F, setback to 65.0 °F
Cooling thermostat	78.0 °F, no setup	78.0 °F, setup to 83.0 °F
Heat/cool performance	eff=100,EER=8.9	COP=3.5,EER=18.0
Economizer?/type	no/NA	no/NA
Duct leaks/conduction losses, total %	11/10	11/10
Peak Gains; IL,EL,HW,OT; W/ft²	0.20/0.04/0.66/0.36	0.15/0.03/0.66/0.36
Added mass?	none	650 ft², 8in cmu
Daylighting?	no	yes, continuous dimming
Infiltration, in²	ELA=135.1	ELA=36.6

Table C.9 provides a summary of the energy consumption together with the sizing of the photovoltaic panels. Lifecycle costs have also been provided in the simulation as shown in this Table. Lifecycle costs have been dealt in a greater detail in the Chapter 5 wherein a discussion on the lifecycle costs computed by this software have been provided.

An important outcome of the simulation was the sizing of photovoltaic panels and area required for the same. In the section dealing with active systems presented later in this report, solar module calculations have been described in greater detail. The summary also outlines the size of the domestic solar hot water systems.

Table C.9 Results of the Simulation

Results:		
Energy cost	0.353$/Therm,0.420$/kWh,3.000$/kW	0.353$/Therm,0.420$/kWh,3.000$/kW
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec
Energy use, kBtu	346439	114430
Energy cost, $	43854	14473
Saved by daylighting, kWh	-	NA
Total Electric (**), kWh	101527	33535
Internal/External lights, kWh	3065/334	2298/251
Heating/Cooling/Fan+Aux, kWh	63014/11297/3347	3839/4557/2120
Heat Pump/Elec. Res., kWh	0/0	3725/114
Hot water/Other, kWh	11180/9290	11180/9290
Peak Electric, kW	68.4	17.1
Fuel, hw/heat/total, kBtu	0/0/0	0/0/0
Emissions, CO2/SO2/NOx, lbs	136452/802/416	45071/265/137
Construction Costs	631963	693096
Life-Cycle Cost	1591436	1154372
Photovoltaics System Summary:		
Description:	Reference Case	Low-Energy Case
PV System Definition Status:	Undefined	Modified
Total PV Array Area, ft² / m²	--	625 / 58
Total PV Rated Output, kW	--	6.8
Total Inverter Rated Capacity, kW	--	8
Total PV System First Cost, $	--	51300

Bsack House Energy-10 Simulation

The data for the simulation for the front house was used to achieve the following results. It is evident from Figures C.66 and C.67 that around 50% of the energy is conserved in this case and like in the front house a good deal of energy is saved in heating the spaces.

Figure C.66 Annual Energy Use

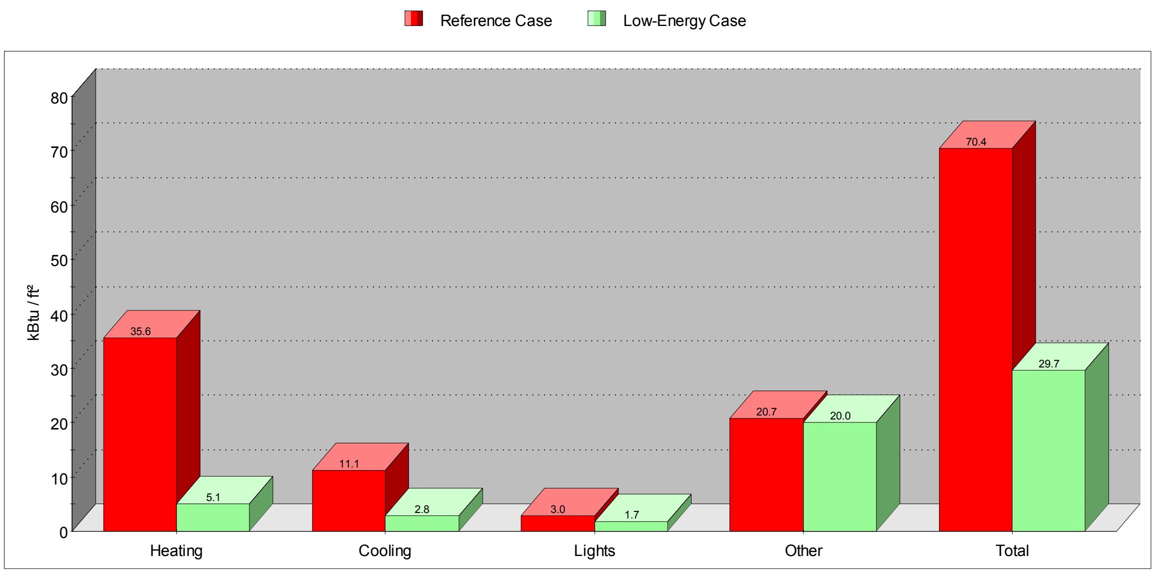
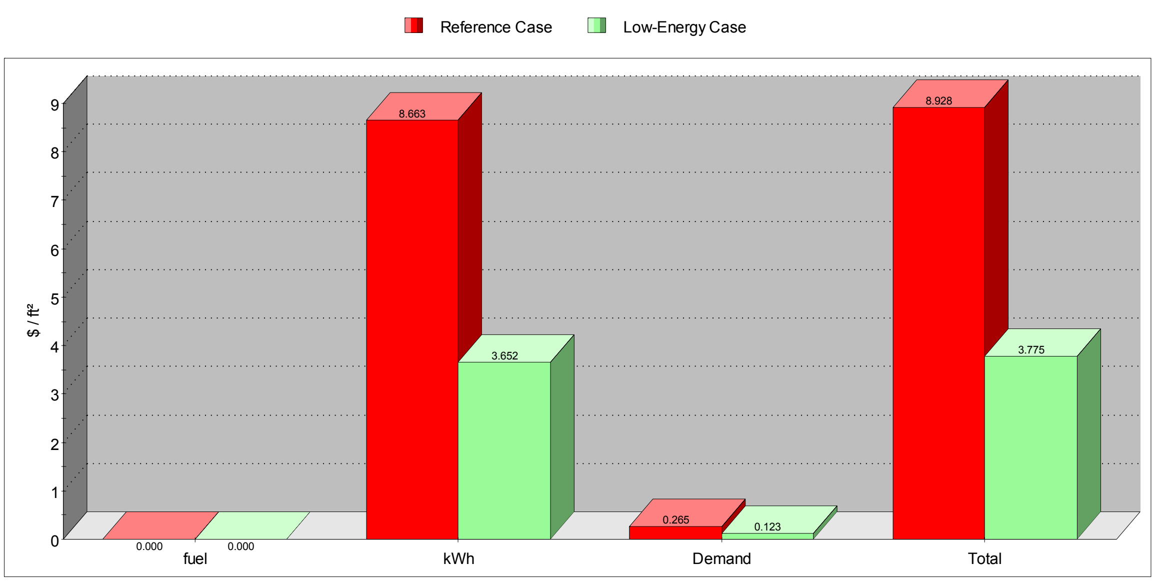


Figure C.67 Annual Energy Cost

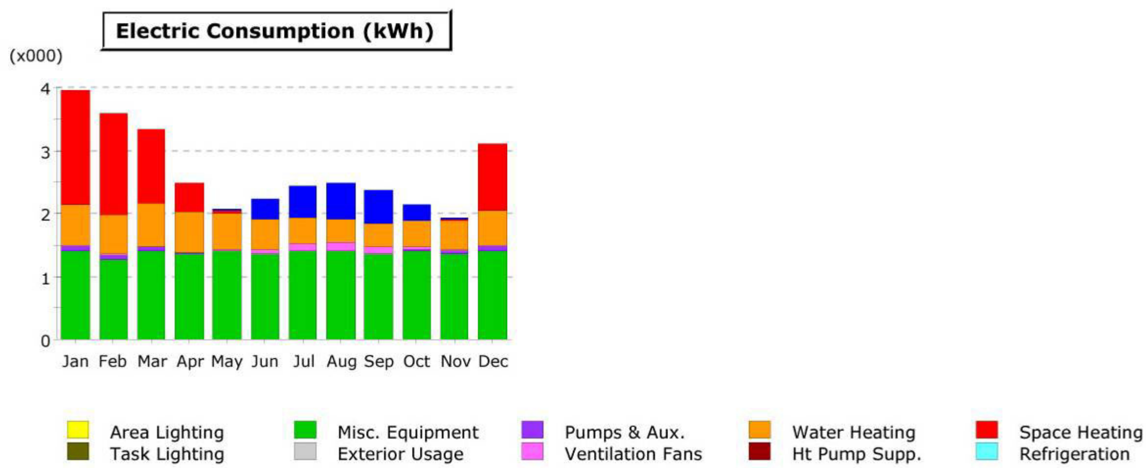


Back House eQuest Simulation

The data for the simulation for the front house was used to achieve the following results. It is evident from that close to 50% of the energy is conserved in this case and like in the front house a good deal of energy is saved in heating the spaces.

Figures C.68 and C.69 illustrate how the electric consumption for the reference case is 32,100 kWh where as the front house has a demand of 25,820 kWh.

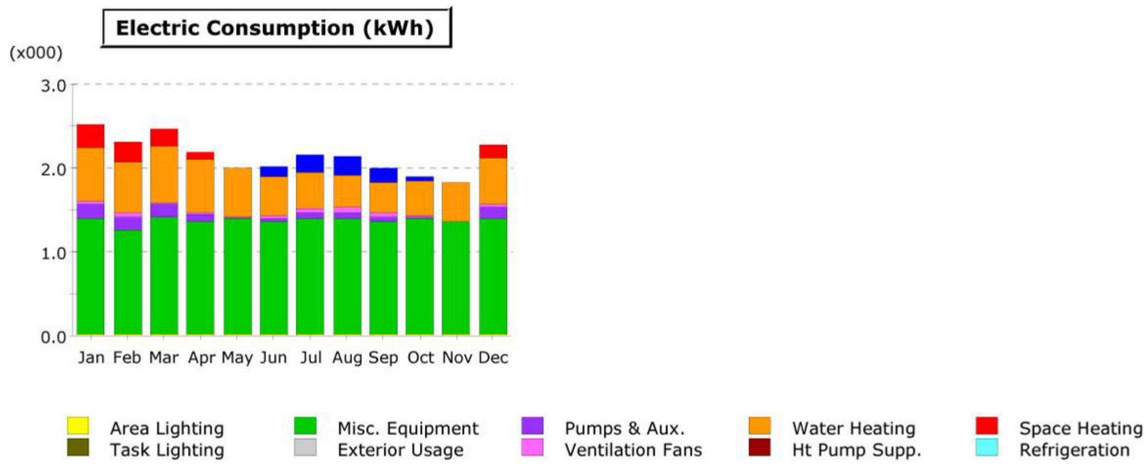
Figure C.68 Energy Consumption by Baseline Case



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	0.02	0.33	0.51	0.57	0.53	0.26	0.03	-	2.24
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.80	1.61	1.17	0.45	0.05	-	-	-	-	-	0.03	1.06	6.16
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.64	0.61	0.68	0.64	0.58	0.47	0.42	0.38	0.36	0.41	0.47	0.56	6.21
Vent. Fans	0.03	0.03	0.02	0.01	0.00	0.07	0.12	0.13	0.12	0.06	0.01	0.02	0.62
Pumps & Aux.	0.07	0.06	0.05	0.02	0.01	0.00	-	0.00	0.00	0.02	0.05	0.07	0.36
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	1.39	1.26	1.40	1.35	1.39	1.35	1.39	1.39	1.35	1.39	1.35	1.39	16.40
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.12
Total	3.95	3.58	3.33	2.47	2.06	2.23	2.44	2.49	2.37	2.14	1.94	3.11	32.10

Figure C.69 Energy Consumption by Low-Energy Case

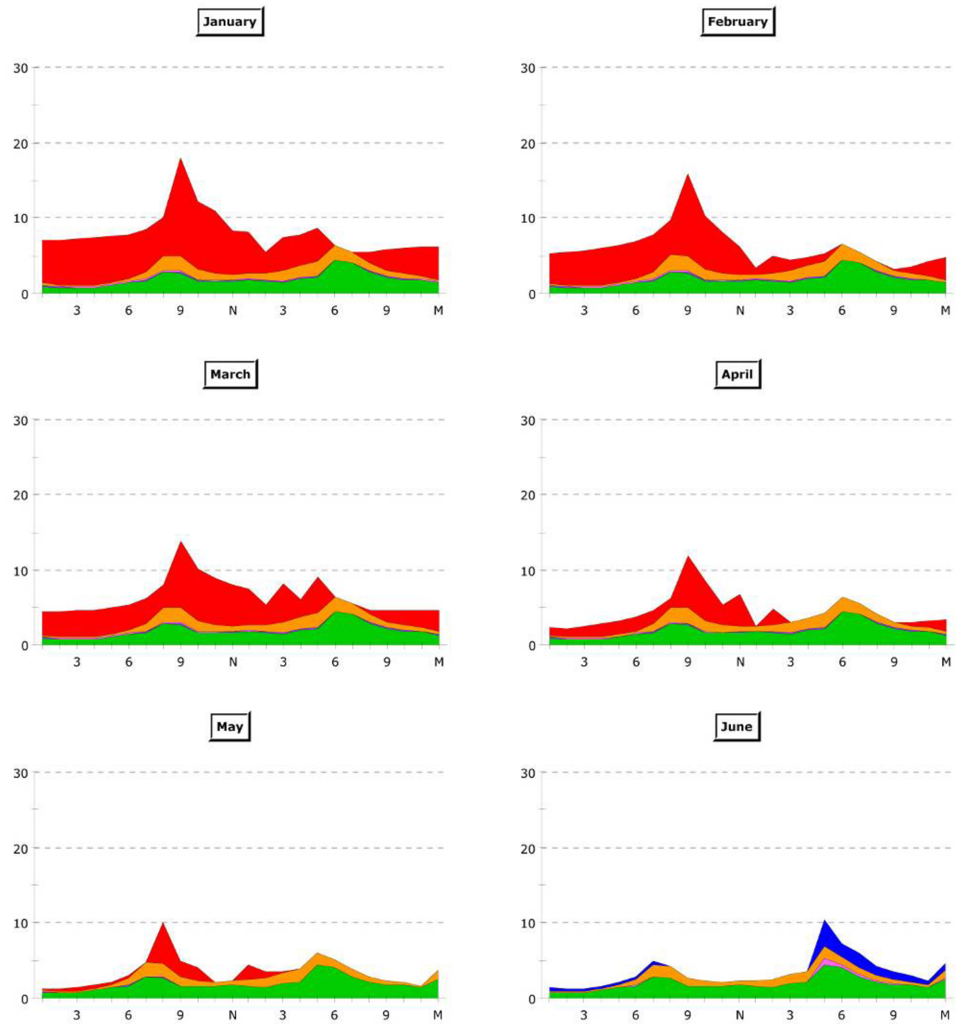


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	0.00	0.12	0.22	0.23	0.18	0.04	0.00	-	0.79
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.27	0.25	0.20	0.09	0.01	-	-	-	-	-	0.00	0.16	0.98
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.64	0.61	0.67	0.64	0.58	0.47	0.42	0.38	0.36	0.41	0.47	0.56	6.20
Vent. Fans	0.05	0.04	0.03	0.01	0.00	0.03	0.06	0.07	0.06	0.02	0.00	0.03	0.39
Pumps & Aux.	0.16	0.15	0.16	0.09	0.01	0.03	0.06	0.07	0.05	0.02	0.00	0.13	0.94
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	1.39	1.26	1.40	1.35	1.39	1.35	1.39	1.39	1.35	1.39	1.35	1.39	16.40
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.12
Total	2.52	2.32	2.47	2.19	2.00	2.01	2.16	2.14	2.00	1.89	1.83	2.28	25.82

Figures C.70 and C.71 show how the profiles of the peak load for the baseline and reference case respectively. The low-energy case shows a lot of savings due to the passive solar heating achieved and hence there is better saving of energy.

Figure C.70 Monthly Electric Peak Load Profiles - Baseline Case



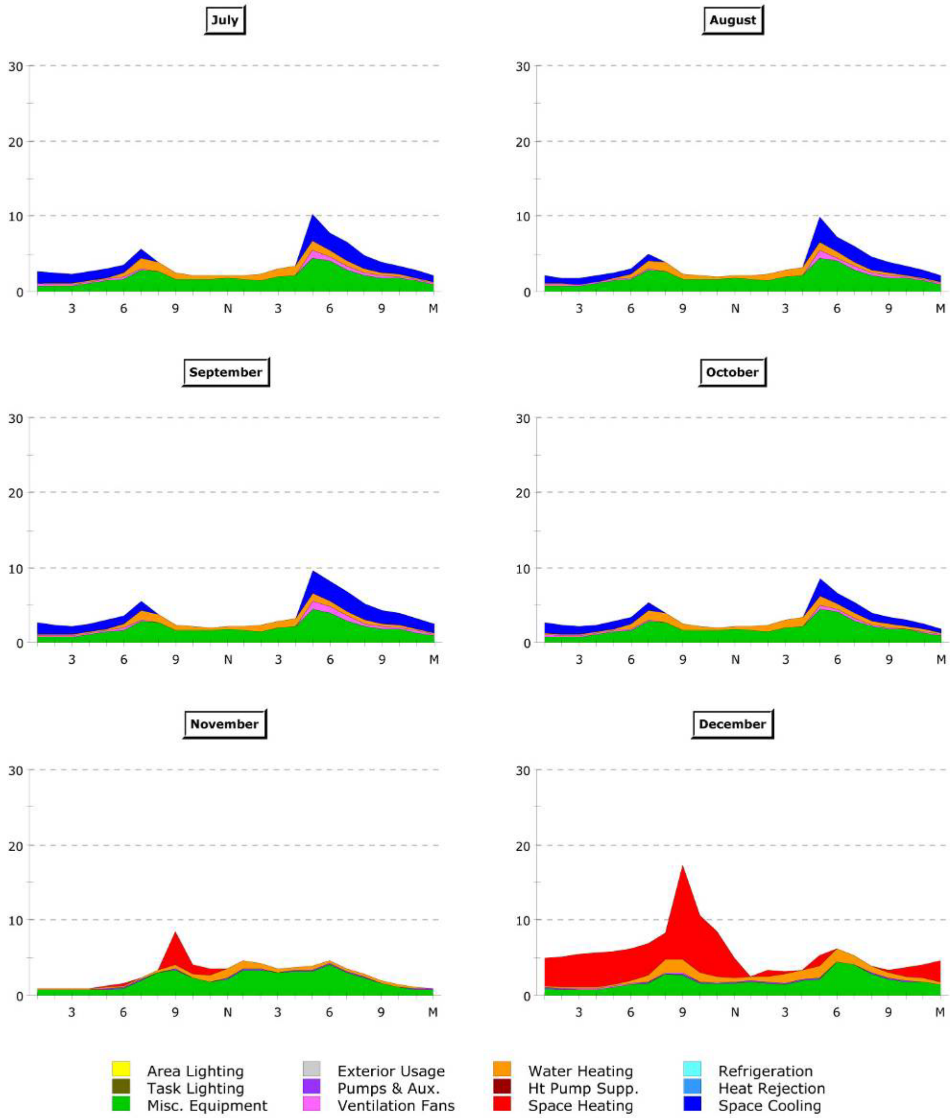
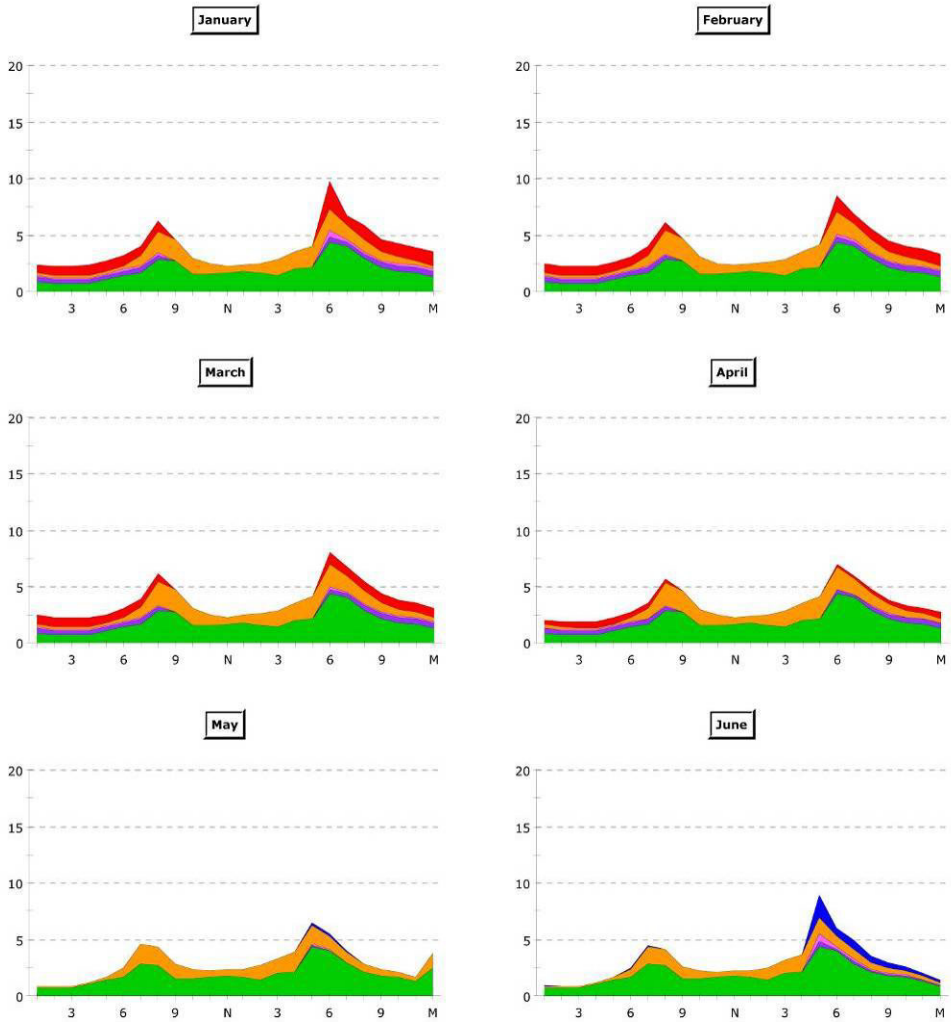

July
August
September
October
November
December
30
20
10
0
3 6 9 N 3 6 9 M
Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

Figure C.71 Monthly Electric Peak Load Profiles- Low-Energy Case



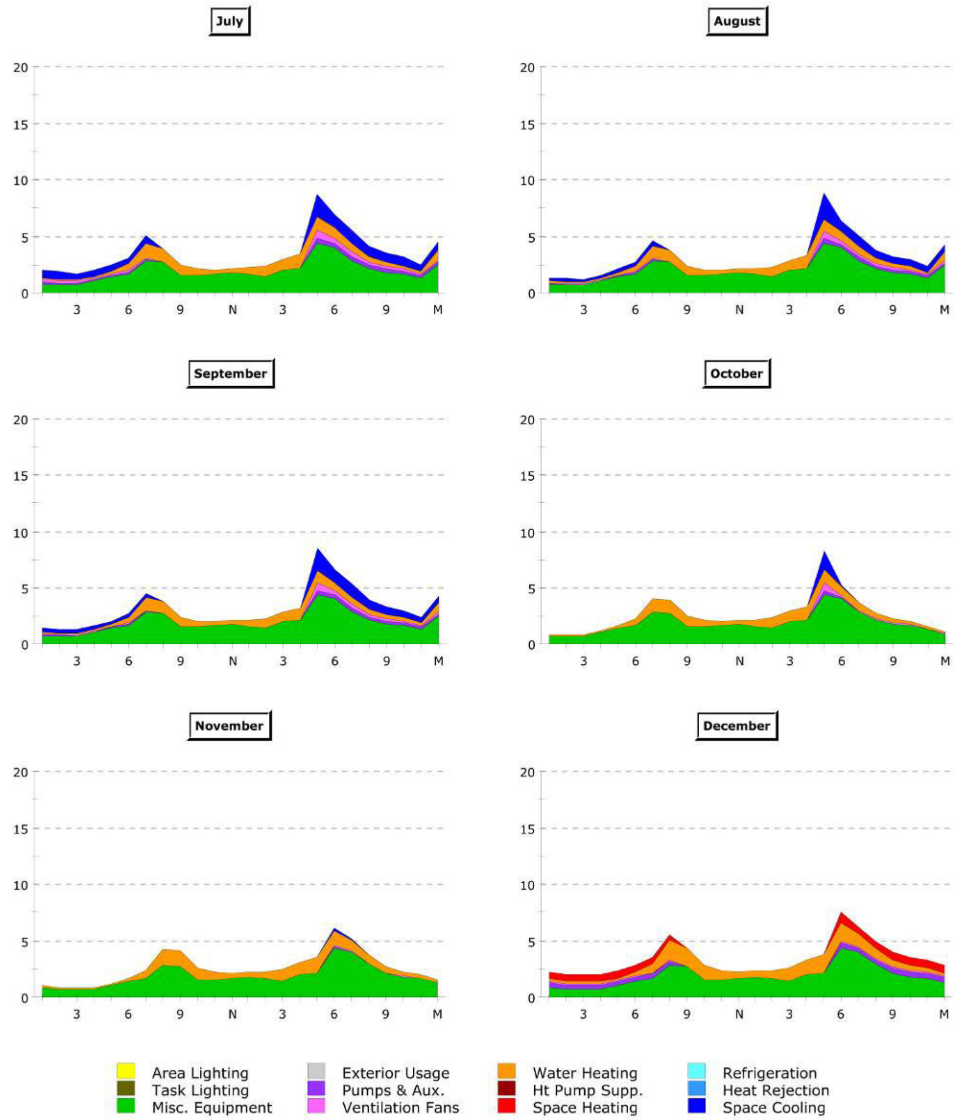

July
August
September
October
November
December
0
5
10
15
20
3
6
9
N
3
6
9
M
Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

Table C.10 Electrical Demand Calculation- Back House

BACK HOUSE			
Description	**Watts X**	**Hrs/Wk =**	**Wh/Wk**
Refrigerator (frost free 16 cu. Ft)	725	168	121,800
Microwave	750	3	2,250
Laptop	50	21	1,050
Television (19")	75	21	1,575
Fans Ceiling (2)	130	18	2,340
Ventilation fan	13	1	13
Washer	500	0.3	150
Cell Phone Charger(2)	6	10	60
Vacuum Cleaner	1000	1	1,000
Lighting	102	25	2,550
others	200	10	2,000
	Total WH/Wk		**134,788**

Table C.11 Calculation of the number of PVL136T Modules Required- Back House

	BACK HOUSE	
1	**Unisolar PVL 136-T**	
2	Energy Use (WH/Wk)(1 apt)	134,788
3	Energy Use (WH/Wk)(2 apt)	269,576
4	Energy Use (WH/day)	38,510
5	Average Sun hours/day for Manhattan KS	6
6	Total KW/Hr required ((Ans 4/Ans 5)/1000)	6.4
7	**Total Energy Use**	**6.4KW**
8	Energy from the panel	136 Watts
9	**No. Of panels**	**47**
12	**Area (18'X15.5"X47)**	**1092sf.**

Appendix D - Economic Analysis

Analysis A

80% mortgage for the front house and 80% for the back house.

Front House

Step 1: Construction Cost and Property Cost

Construction Cost

Main house = $94.62/sf (from Table 5.1)

Main house: 2,600 sf Upper floors + 1,300 sf Basement = $246,014

Property Cost (Source: http://gis.rileycountyks.gov/website/rileyco/viewer.htm: 04/02/'08)

= $ 39,380

Total Cost = $ 285,394

Step 2: Mortgage & Down payment

Use Assumption: 80% mortgage & 20% Down payment

Assume: $ 1,200 for transaction cost

Down payment: $ 285,394 X 0.2 = $ 57,079

Mortgage: $ 285,394 X 0.8 = $228,315.2

Transaction costs = $ 1,200

Total Cost = $229,515.2

Step 3: Principal Interest (PI)

Use: 30 year loan @ 6.5%

Total Mortgage = $229,515.2

(http://finance.move.com/HomeFinance/calculators/mortgagepayment.asp?calculate=True&submit1=Calculate&lnksrc=FINLRMORTCALC002&loanamount=245%2C948.8&InterestRate=0.065&TermOfLoan=30&x=16&y=10&poe=homestore&gate=google&source=a12661: date 04.02.'08)

Monthly PI= $ **1,451**

Step 4: Property Tax (T)

Mill Levy X Assessed Value = Property tax

Assessed value = Assume 11.5% of total cost = $ 285,394X 0.115 = $32820.31 /1000

Mill Levy = Manhattan, KS 2006 was $110.571

(http://www.rileycountyks.gov/documents/County%20Clerk/Mill%20Levy%20Sheets/LevyCertification%20Tax%20Units.pdf : 04/02/'08)

$110.571X 32.82= $ 3,629

Monthly T= $ 302.41

Step 5: Insurance (I) (http://www.joemaggio.com/r_mortgage-calculator_rentvsbuy.asp : 04/02/'08)

Year= 0.5% of $285,394= $ 1427

Monthly I= $ 119

Step 6: PITI

PI + T + I = Monthly Cost

1,451 + $ 302.41 + $ 119 = Monthly Cost

PITI= $ 1,872

Step 7: Rental Profit (refer back house calculation)

3 bedrooms X 450(Basement) = $1350 + $393 (see back house calculation)

Total Rental Profit = $1,743

Step 8: Adjusted Monthly Cost

PITI - Rental profit = $ 1,872 - 1,743 = $ 129

Adjusted Monthly Cost= $ 129

Step 9: Estimated Minimum Annual Income to be used only for housing

($ 129/.25) X 12 = $ 6,192

Annual Housing Expenses = $ 6,200

(Rounded to the nearest hundred dollars)

Back House

Step 1: Construction Cost

Construction Cost

Main house = $137.4 per sq ft (from Table 5.2)

Two apartments @ 1,232 sf each **= $169,363**

Total Cost = $169,363

Step 2: Mortgage & Down payment

Use Assumption: 80% mortgage &20% Down payment

Assume: $ 1,200 for transaction cost

Down payment: $ 169,363X0.2 = $ 33,873

Mortgage: $ 169,363 X 0.8 = $135,490.4

Transaction costs = $ 1,200

Total Cost = $136,690.4

Step 3: Principal Interest (PI)

Use: 30 year loan @ 7.5%

Total Mortgage = $157495.2

Monthly PI= $ 955.76

Step 4: Property Tax (T)

Mill Levy X Assessed Value = Property tax

Assessed value = Assume 11.5% of total cost = $ 169,363 X 0.115 = $ 19,477/1000

Mill Levy for Manhattan, KS 2006 was $110.571

(http://www.rileycountyks.gov/documents/County%20Clerk/Mill%20Levy%20Sheets/LevyCertification%20Tax%20Units.pdf: 04/02/'08)

$110.571 X 19.5= $ 2,156.11

Monthly T= $ 180

Step 5: Insurance (I)

Year = 0.5% of $169,363= $847

Monthly I= $ 70.6

Step 6: PITI

PI + T + I = Monthly Cost

$956 + $ 180 + $ 71 = Monthly Cost

Monthly PITI= $ 1207

Step 7: Rental Income

4 bedrooms X $450 = $1800

Income= $ 1800

Step 8: Maintenance Cost both front and back house rental units

Assume: $200 / month

Step 8: Adjusted Monthly Income

Rent-PITI-Maintenance Cost

$1,800 - $1207 - $200= + $393

Adjusted Monthly Cost = + $393 (PROFIT)

Analysis B

90% mortgage for the front house and 80% for the back house.

Front House

Step 1: Construction Cost and Property Cost

Construction Cost

Main house = $94.62 / sf (from Table 5.1)

Main house: 2,600 sf. Upper floors+1,300SF Basement = $246,014

Property Cost (Source: http://gis.rileycountyks.gov/website/rileyco/viewer.htm: accessed on 04.02.'08)

= $ 39,380

Total Cost = $ 285,394

Step 2: Mortgage & Down payment

Use Assumption: 90% mortgage & 10% Down payment

Assume: $ 1,200 for transaction cost

Down payment: $ 285,394 X 0.1 = $ 28,539.4

Mortgage: $ 285,394 X 0.9 = $256,854.6

Transaction costs = $ 1,200

Total Cost = $258,054.6

Step 3: Principal Interest (PI)

Use: 30 year loan @ 6.5%

Total Mortgage= $256,854.6

(http://finance.move.com/HomeFinance/calculators/mortgagepayment.asp?calculate=True&submit1=Calculate&lnksrc=FINLRMORTCALC002&loanamount=245%2C948.8&InterestRate=0.065&TermOfLoan=30&x=16&y=10&poe=homestore&gate=google&source=a12661: accessed on 04.02.'08)

Monthly PI = $ 1,623.50

Step 4: Property Tax (T)

Mill Levy X Assessed Value = Property tax

Assessed value = Assume 11.5% of total cost = $ 285,394 X 0.115 = $32,820.31 /1000

Mill Levy for Manhattan, KS 2006 was $110.571

(http://www.rileycountyks.gov/documents/County%20Clerk/Mill%20Levy%20Sheets/LevyCertification%20Tax%20Units.pdf: 04/02/'08)

$110.571X 32.82= $ 3,628.94

Monthly T= $ 302.41

Step 5: Insurance (I) (http://www.joemaggio.com/r_mortgage-calculator_rentvsbuy.asp: 04/02/'08)

Year= 0.5% of 285,394= $ 1426.97

Monthly I= $ 119

Step 6: PITI

PI+ T + I = Monthly Cost

1,623.5+ $ 302.41 + $ 119 = Monthly Cost

PITI= $ 2044.91

Step 7: Rental Profit

3 bedrooms X450(Basement) = $1350 + $393 (backhouse from next page)

Total Rental Profit = $1743

Step 8: Adjusted Monthly Cost

PITI- Rental profit = $ 2044.91- 1743= $ 302

Adjusted Monthly Cost= $ 302

Step 9: Estimated Minimum Annual Income to be invested in housing

($302/.25)X12= $ 14,500

Annual Housing Expenses = $ 14,500

(Rounded to the nearest hundred dollars)

__Back House__

Step 1: Construction Cost

Construction Cost

Main house = $137.4 per sq ft (from Table 5.2)

Two apartments @ 1,232 sf each = **$169,363**

<u>**Total Cost = $169,363**</u>

Step 2: Mortgage & Down payment

Use Assumption: 80% mortgage &20% Down payment

Assume: $ 1,200 for transaction cost

Down payment: $ 169,363X0.2 = $ 33,873

Mortgage: $ 169,363 X 0.8 = $135,490.4

Transaction costs = $ 1,200

<u>**Total Cost = $136,690.4**</u>

Step 3: Principal Interest (PI)

Use: 30 year loan @ 7.5%

Total Mortgage = $157495.2

<u>**Monthly PI= $ 955.76**</u>

Step 4: Property Tax (T)

Mill Levy X Assessed Value = Property tax

Assessed value = Assume 11.5% of total cost = $ 169,363 X 0.115 = $ 19,477/1000

Mill Levy for Manhattan, KS 2006 was $110.571

(http://www.rileycountyks.gov/documents/County%20Clerk/Mill%20Levy%20Sheets/LevyCertification%20Tax%20Units.pdf: 04/02/'08)

$110.571 X 19.5= $ 2,156.11

<u>**Monthly T= $ 180**</u>

Step 5: Insurance (I)

Year = 0.5% of $169,363= $847

<u>**Monthly I= $ 70.6**</u>

Step 6: PITI

PI + T + I = Monthly Cost

$956 + $ 180 + $ 71 = Monthly Cost

Monthly PITI= $ 1207

Step 7: Rental Income

4 bedrooms X $450 = $1800

Income= $ 1800

Step 8: Maintenance Cost both front and back house rental units

Assume: $200 / month

Step 8: Adjusted Monthly Income

Rent-PITI-Maintenance Cost

$1,800 - $1207 - $200= + $393

Adjusted Monthly Cost = + $393 (PROFIT)

The Tables below show the construction costs for an energy efficient house using the specifications as given by Energy-10 simulation. It should be noted that *'Prices listed are costs that include overhead and profit of the installing contractor. Total model costs include an additional markup for general contactors, overhead and profits and fees specific to class of contractors.'* (RS Means, 2008, p. 4)

Table D.12 Cost of Front House

Main Building			**Cost per S.F Living Area**		
Cost per Square Foot of Living Area (Ans. A below)				$	62.85
Basement Addition		100% Finished		$ +	15.55
Main Building: Adjusted cost per S.F of Living Area				**$**	**78.4**
MAIN BUILDING TOTAL COST	**$78.4/SF**	**X**	**2,600**	=	**203840.00**
External Doors (Calculation B from table C.2 below)					4600.00
Internal Doors (Calculation C from table C.2 below)					8756.00
Windows (Calculation D from table C.2 below)					44420.00
Kitchen and bathroom calculations					
Upper Floor Kitchen				=	5771.00
Upper Floor Baths 3 Full @ $5,129				=	15387.00
B'ment Floor Baths 2 Full @ $5129				=	10258.00
Additional B'ment Kitchen				=	5771.00
ADJUSTED TOTAL BUILDING COST				=	**298803.00**
Cost for excavation, spread and strip footings and Underground piping				**X**	**2.40%**
Cost				**=**	**305975**
Location Factor (Topeka, Kansas)				**X**	**0.79**
Location Replacement Cost				**=**	**$241,720**
Architect/Designer Fees				**X**	**10.00%**
FINAL BUILDING COST					**$265,892**

Table D.13 Cost of Building Assembly for Front House

WALL
Brick Vineer Wall (pp:166 RSMeans Assembly)
Standard 2X6= 23.60 /sft Increased insulation costs: 3.85 (sprayed insulation in 2x6 walls)+- 0.96 (existing insulation): **Total Cost = $26.5**
Wood Siding Wall (pp:196 RSMeans Assembly)
Standard 2X6= 8.3 /sft
Increased insulation costs: 3.85 (sprayed insulation in 2x6 walls)- 0.96 (existing
Total Cost = $11.19
Wood Siding=88% Brick Vineer=12%
WALL CONSTRUCTION COST=0.12(26.5)+0 .88(11.19)=$ 13/sft
FLOOR
Flooring (pp: 102 RSMeans Assembly)
15'X15' BAYS, S. LOAD 40 P.S.F = $12.67/sft
Bamboo Flooring = $5.90/sft (pg382: RSMeans:Green Building)
Total= $ 18.57
ROOF
Flooring (pp: 109 RSMeans Assembly)
2"X10"= $3.75/sft
Insulation costs: 11.85 (fiberglass) + 0.81(radiant barrier)+ 1.13
Asphalt Shingles = $1.47/sft
Total Cost= $ 18.45/sft
PARTITIONS (p: 230 RSMeans Assembly Cost Data)
Dry wall partitions,5/8" F.R.I sides, 2"X4" Studs, 16" O.C= **$2.83/sft**
PAINTS (p: 254 RSMeans Assembly Cost Data)
Walls ans Ceilings roller wash, primer and two coates = **$1.27/sft**
CEILINGS (p: 382 RSMeans Green Building)
Acoustical Tiles= **$1.49/sft**
ELECTRICAL WORKS (p: 444 RSMeans Green Building)
Elecrical Works = **S5.31/sft**
AIR CONDITIONING/HEATING DUCT WORKS
Duct works = $ **1.93sft**
A)TOTAL COST PER SQUARE FOOT(without doors and windows)= $62.85
EXTERNAL BIRCH DOORS (pp.209 RSMeans Assembly)
3 nos. External 3'X7' door = $1,390X3 = $ 4,170
Wood Storm and Screen = $430
B)Total Cost for Doors: $4,600
INTERNAL DOORS (pp.209 RSmeans Assembly)
C)22 Birch doors with metal frame @ $398= $8,756
WINDOWS
WINDOWS SYSTEM:Direct gain double glazed (pp.313 RSMeans Assembly Cost Data)
South : 11 Three Panel Wide@ 2,700 each = **$ 29,700**
Others: 20 Casement Insulated Glass Windows @ 736= $14,720 (p 202: RSMeans Assembly) = **$14,720**
D)Total cost for windows = $ 44,420

Table D.14 Cost of Back House

Main Building				Cost per S.F Living Area	
Cost per Square Foot of Living Area (from answer A below)				$	64.65
100% finished basement				$ +	30.75
Main Building: Adjusted cost per S.F of Living Area				**$**	**95.4**
MAIN BUILDING TOTAL COST	**$95.4/SF**	**X**	**656**	=	**62,582.00**
External Doors (Calculation B from table C.4 below)					3,170.00
Internal Doors (Calculation C from table C.4 below)					3,184.00
Windows (Calculation D from table C.4below)					13,889.00
Kitchen and bathroom calculations					
Kitchen				=	5,771.00
Baths 1 Full @ $5,129 1 half @ 3,107				=	8,236.00
ADJUSTED TOTAL BUILDING COST				=	**96,832.00**
Cost for excavation, spread and strip footings and Underground piping				**X**	**2.40%**
Cost				**=**	**99,156.00**
Town House (Common wall Factor)				**X**	**0.95**
Cost				**=**	**94,198.00**
Location Factor (Topeka, Kansas)				**X**	**0.79**
Location Replacement Cost				**=**	**$74,417**
Architect/Designer Fees				**X**	**10.00%**
FINAL BUILDING COST					**$81,859**
FINAL BUILDING COST FOR TWO APARTMENTS				**X 2**	**$163,717**

Table D.15 Cost of Building Assembly for One Back House

WALL
Brick Vineer Wall (pp:166 RSMeans Assembly)
Standard 2X6= 23.60 /sft Increased insulation costs: 3.85 (sprayed insulation **Total Cost = $26.5**
Wood Siding Wall (pp:196 RSMeans Assembly)
Standard 2X6= 8.3 /sft
Increased insulation costs: 3.85 (sprayed insulation
Total Cost = $11.19
Wood Siding=76% Brick Vineer=24%
WALL CONSTRUCTION COST=0.24(26.5)+0 .76(11.19)=$ 14.8/sft
FLOOR
Flooring (pp: 102 RSMeans Assembly)
15'X15' BAYS, S. LOAD 40 P.S.F = $12.67/sft
Bamboo Flooring = $5.90/sft (pg382: RSMeans:Green Building)
Total= $ 18.57
ROOF
Flooring (pp: 109 RSMeans Assembly)
2"X10"= $3.75/sft
Insulation costs: 11.85 (fiberglass) +
Asphalt Shingles = $1.47/sft
Total Cost= $ 18.45/sft
PARTITIONS (p: 230 RSMeans Assembly Cost Data)
Dry wall partitions,5/8" F.R.I sides, 2"X4" Studs, 16" O.C= **$2.83/sft**
PAINTS (p: 254 RSMeans Assembly Cost Data)
Walls ans Ceilings roller wash, primer and two coates = **$1.27/sft**
CEILINGS (p: 382 RSMeans Green Building)
Acoustical Tiles= **$1.49/sft**
ELECTRICAL WORKS (p: 444 RSMeans Green Building)
Elecrical Works = $**5.31/sft**
AIR CONDITIONING/HEATING DUCT WORKS
Duct works = $ **1.93sft**
A)TOTAL COST PER SQUARE FOOT(without doors and windows)= $64.65
EXTERNAL BIRCH DOORS (pp.209 RSMeans Assembly)
2 nos. External 3'X7' door = $1,390X2 = $ 2,740
Wood Storm and Screen = $430
B)Total Cost for Doors: $3,170
INTERNAL DOORS (pp.209 RSmeans Assembly)
C) 8 Birch doors with metal frame @ $398= $3,184
WINDOWS
WINDOWS SYSTEM:Direct gain double glazed (pp.313 RSMeans Assembly Cost Data)
South : 11 One Panel Wide(2'6"X5')@ 995 each = **$10,945**
Others: 4 Casement Insulated Glass Windows @ 736= $14,720 (p 202: RSMeans Assembly) = **$2,944**
D)Total cost for windows = $13,889

Table D.16 Data for BIPV Payback Period

Years	Factor	PV		Conventional
		Operating cost	Total Cost/Year	Utility Cost/Year
1	0.971	365.6	57.642	0.318
2	1.913	731.2	58.008	1.252
3	2.829	1096.8	58.374	2.775
4	3.717	1462.4	58.739	4.863
5	4.580	1828	59.105	7.489
6	5.417	2193.6	59.470	10.630
7	6.230	2559.2	59.836	14.263
8	7.020	2924.8	60.202	18.366
9	7.786	3290.4	60.567	22.917
10	8.530	3656	60.933	27.897
11	9.253	4021.6	61.298	33.286
12	9.954	4387.2	61.664	39.064
13	10.635	4752.8	62.030	45.215
14	11.296	5118.4	62.395	51.720
15	11.938	5484	62.761	58.563
16	12.561	5849.6	63.126	65.728
17	13.166	6215.2	63.492	73.199
18	13.754	6580.8	63.858	80.963
19	14.324	6946.4	64.223	89.005
20	14.877	7312	64.589	97.311

Table D.17 Data for Geothermal Payback Period

		Geothermal	Conventional
Years	Factor	Total Operating Cost/Year	Operating Cost/Year
1	0.971	23.550	15.357
2	1.913	26.641	23.469
3	2.829	31.682	36.700
4	3.717	38.588	54.826
5	4.580	47.276	77.632
6	5.417	57.668	104.909
7	6.230	69.688	136.458
8	7.020	83.262	172.087
9	7.786	98.321	211.613
10	8.530	114.797	254.858
11	9.253	132.625	301.652
12	9.954	151.743	351.832
13	10.635	172.091	405.243
14	11.296	193.613	461.732
15	11.938	216.253	521.156
16	12.561	239.958	583.376
17	13.166	264.678	648.260
18	13.754	290.363	715.680
19	14.324	316.969	785.512
20	14.877	344.449	857.641