ARCTIC/SUBARCTIC URBAN HOUSING: RESPONSES TO THE NORTHERN CLIMATES

by

JOHN FREDERICK ROSS
B. Arch., University of California, Berkeley, 1967

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARCHITECTURE

in
THE FACULTY OF GRADUATE STUDIES (School of Architecture)

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA
May, 1977

© John Frederick Ross, 1977
In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of ARCHITECTURE

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date 28 APRIL, 1977
This study investigates the effects of the arctic and subarctic climatic conditions on the built environment, urban housing in particular. The method of research and development of this thesis has been through a literature search coupled with my own working/design experience in the North (Fairbanks, Alaska) for three years.

The thesis is in three parts (chapters 2, 3, and 4). The first part makes a comparison of the climatic conditions in the different northern climatic zones within the state of Alaska, as well as comparing these to more southern climatic zones.

The second part (main body of the thesis) investigates the building design responses (solutions) to the varied climatic conditions: solar radiation, temperature, precipitation, wind, and special climatic conditions (humidity/moisture potential, blowing snow, permafrost, and frost heave). This analysis is organized into "planning levels". Four planning levels are established which deal with 1) site layout/circulation patterns, 2) building size, shape, and orientation, 3) activity/space arrangement, and 4) detailing of the building fabric.

Using the parameters established in part 2, planning level 1, part 3 illustrates a townsitew layout for a specific site, the Willow Site in subarctic Alaska where the new Alaska State Capital is to be located.

The majority of people who live in the northern urban areas look to the south for their housing styles and designs as well as assess housing quality by "southern standards". Presently there are few ways for people living in the North to evaluate the quality of housing for that particular climate except through
trial and quite often error. This thesis produces an ordered listing of building/housing responses to the northern climates which can be disseminated to the public who can then better assess housing performance and quality for their particular physical environment. The information contained within this thesis would also be of use to professionals in arriving at design decisions for housing/building in northern areas.
TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

1.1 THE PROBLEM
   1.1.1 Socio-Cultural Background
   1.1.2 Existing Urban/Suburban Environment
   1.1.3 The Willow Site: New Capital City

1.2 GOALS

1.3 SCOPE

1.4 METHODOLOGY

1.5 APPLICATION

1.6 IMPLEMENTATION

1.7 DEFINITIONS

1.8 REFERENCES

CHAPTER 2: CLIMATIC COMPARISON

2.1 INTRODUCTION

2.2 SOLAR RADIATION
   2.2.1 Objective/Background
   2.2.2 Apparent Sun Path (Altitude & Azimuth)
   2.2.3 Albedo
   2.2.4 Cloud Cover
   2.2.5 Implications

2.3 TEMPERATURE
   2.3.1 Objective
   2.3.2 Duration of Cold Extremes
   2.3.3 Seasonal Temperature Differences: Average and Extreme
   2.3.4 Diurnal Temperature Variations
   2.3.5 Implications

2.4 PRECIPITATION
   2.4.1 Objective
   2.4.2 Normal Yearly Precipitation
   2.4.3 Extreme precipitation Amounts Over Short Periods
   2.4.4 Snow Cover Amount and Duration
   2.4.5 Implications

2.5 WIND
   2.5.1 Objective
   2.5.2 Mean Winter Wind Speed and Direction
   2.5.3 Mean Summer Wind Speed and Direction
   2.5.4 Maximum Wind Speeds and Directions
   2.5.5 Katabatic Wind
   2.5.6 Implications

2.6 SPECIAL CLIMATIC CONDITIONS
   2.6.1 Objective
   2.6.2 Humidity/Moisture Potential
2.6.3 Blowing Snow
2.6.4 Permafrost
2.6.5 Active Layer/Frost Heave

2.7 SUMMARY

2.8 REFERENCES

CHAPTER 3: BUILDING DESIGN RESPONSES

3.1 INTRODUCTION

3.2 PLANNING LEVEL 1: SITE LAYOUT/CIRCULATION PATTERNS
  3.2.1 Objective
  3.2.2 Solar Radiation
  3.2.3 Temperature
  3.2.4 Precipitation
  3.2.5 Wind
  3.2.6 Special Climatic Conditions (Blowing Snow)
  3.2.7 Summary
  3.2.8 References

3.3 PLANNING LEVEL 2: BUILDING SIZE, SHAPE, AND ORIENTATION
  3.3.1 Objective
  3.3.2 Solar Radiation
  3.3.3 Temperature
  3.3.4 Precipitation
  3.3.5 Wind
  3.3.6 Special Climatic Conditions (Blowing Snow)
  3.3.7 Summary
  3.3.8 References

3.4 PLANNING LEVEL 3: ACTIVITY/SPACE ARRANGEMENT
  3.4.1 Objective
  3.4.2 Solar Radiation
  3.4.3 Temperature
  3.4.4 Precipitation
  3.4.5 Wind
  3.4.6 Special Climatic Conditions (Blowing Snow)
  3.4.7 Summary
  3.4.8 References

3.5 PLANNING LEVEL 4: DETAILING OF THE BUILDING FABRIC
  3.5.1 Objective
  3.5.2 Solar Radiation
  3.5.3 Temperature
  3.5.4 Precipitation
  3.5.5 Wind
  3.5.6 Special Climatic Conditions
    A. Humidity/Moisture Potential
    B. Blowing Snow
    C. Permafrost
    D. Frost Heave
  3.5.7 Summary
  3.5.8 References
ACKNOWLEDGEMENT

I wish to extend my thanks to those who have worked within my subject area and helped through conversations and/or the supplying of informative literature: Boris Culjat (Ralph Erskine's firm in Sweden), Burgess Ledbetter (CRREL, Hanover, N.H.), and the National Research Council of Canada. Thanks go to Dr. John Hay of the Geography Department for review on the portion of my thesis dealing with the climatic analysis along with supplying the northern radiation data. Thanks to Natalie Hall of the Architecture Reading Room for her help in the literature search. Special thanks go to my thesis committee who had the major task of helping me bring all my material together into a cohesive format: Ray Cole, Wolfgang Gerson, and my mentor, Paul Wisniki.
CHAPTER 1
INTRODUCTION

1.1 THE PROBLEM
   1.1.1 Socio-Cultural Background
   1.1.2 Existing Urban/Suburban Environment
   1.1.3 The Willow Site: New Capital City

1.2 GOALS

1.3 SCOPE

1.4 METHODOLOGY

1.5 APPLICATION

1.6 IMPLEMENTATION

1.7 DEFINITIONS

1.8 REFERENCES
1.1 THE PROBLEM

1.1.1 Socio-Cultural Background

When dealing with the built environment in northern Canada and Alaska, one is confronted with climatic as well as cultural differences. The design for the need of an indigenous population which retains its historic cultural patterns, and the design for the needs of "newcomers" from the south with differing cultural origins and patterns present differing criteria for designing in the harsh northern climates. This thesis focuses on those people who are tied into the mainstream of the more southern culture, those who identify with the culture and built environment of northern U.S. and southern Canadian cities. My concern is to let these people know the effects of the more extreme climatic conditions on their housing image which normally responds to their needs under more temperate environmental conditions.

"Given a certain climate, the availability of certain materials, and constraints and capabilities of a given level of technology, what finally decides the form of a dwelling, and molds the spaces and their relationships, is the vision that people have of the ideal life. The environment sought reflects many socio-cultural forces, including religious beliefs, family and clan structure, social organization, way of gaining a livelihood, and social relations between individuals. This is why solutions are much more varied than biological needs, technical devices, and climatic conditions, and also why one aspect may be more dominant in one culture than it is in others. Buildings and settlements are the visible expression of the relative importance attached to different aspects of life and the varying ways of perceiving reality."1

One major force slowing the acceptance of a housing style or design which is unique to the sub-arctic climate lies in the socio-cultural make up of the majority of people living in the sub-arctic urban areas. These people have strong socio-cultural ties to the mainstream of American culture which is
centered in the more southern latitudes of the continental United States. These people still look to the "south" for their housing styles and designs as well as assess housing quality by "southern standards" only slightly modified.

"A tricky problem that sometimes bedevils the arctic designer is to determine what constitutes a proper house. For many people the "ideal dwelling" is identical to whatever is in fashion "stateside": if this means Ranch-Style-with-Sliding-Glass-Patio-walls, so be it. If it means New-England-Salt-Box, that too can be done. Believe it or not, there are colonnaded Southern Colonial mansions in Anchorage and Fairbanks."²

A look at the housing in the major cities in Alaska, one can see the same designs and styles as the housing in the "lower 48" modified by technical solutions to make them work better in the North, such as increased insulation, more window panes, etc. The circulation patterns, site layouts, and building sizes, shapes, and orientations are nearly identical to those in the "lower 48" showing little design response to the northern sub-arctic climatic conditions.

The local media helps to perpetuate this housing image with articles written in the "lower 48" showing housing which would have difficulties adapting to the sub-arctic environment. Articles on the following pages are from the Fairbanks Daily News-Miner³ and the Anchorage Times.⁴
LANCHE HOUSE—There is a limited amount of brick on the facade of this three-bedroom ranch house, with three windows in the living room, an interesting departure from the usual picture window arrangement. The garage can be for either one or two cars without detracting from the exterior appearance of the house.

**House of the week**

**Good planning adds space**

By ANDY LANG

A compact floor plan that takes advantage of the concept of open planning makes the interior of this ranch seem more spacious than its 1,234 square feet of habitable area.

At the front of the house, the living room and dining room run together for 26 feet. At the rear, the kitchen and family room are similarly arranged along the same distance. The result is a feeling of size that ordinarily might not be experienced in a house with such modest dimensions. This must be considered a plus for most persons, since the amount of living space has a bearing on construction costs.

Should even further budget economies be necessary, the plan can be adjusted downward, as suggested by architects Herman York and Raymond Schenke. The private bathroom for the main bedroom can be omitted, as can the lavatory off the laundry room behind the garage. Both of these spaces could then be used as walk-in storage areas.

The long sweep of the family room and kitchen makes for a feeling of open space, but the kitchen is self-contained with its principle work areas hidden from view. Access is provided from the family room to the rear terrace and, to make matters more convenient, a pass-through serving shelf is between the kitchen and the outdoor dining portion of the terrace.

Beyond the kitchen and still convenient to the rear part of the lot is the laundry, stairway to the basement, mud closet, bathroom, and garage. Should it be possible to hang clothes and linens in the sun, this can be done with convenience in this layout.

**FLOOR PLAN**—No waste space in this floor layout. A minimum amount of hallway in the bedroom area is part of the arrangement to utilize as much available space as possible, thus permitting the rooms to be larger than might otherwise have been possible within modest dimensions.

**FAMILY ROOM**—Portions of the family room, dining area, and kitchen are shown in this artist's rendering. Sliding glass doors lead to a rear terrace.
By ANDY LANG

A Colonial design encloses a modern floor plan in this classic three-bedroom house. It is planned to fit in a lot with adherence to frontage. The siding is a blend of the charm of the past while the arrangement of the rooms accommodates the lifestyle of the present. It is a Colonial blend sometimes known as a “split facade,” with a split entry that prevents excessive exposure to the street and space.

Although it has only 1200 square feet of livable area on the main living level, the arrangement on extra storage and laundry space, and ease of access to the lower level. The charm of Colonial styling is evident in the gabled carport, entrance, the shuttered windows, and the facade of the house. The design is eraly American touches abound in a gracefully styled house.
Supply and Demand Verses Housing Quality

There are other limitations in achieving housing quality which are unique in the arctic and sub-arctic environment. The supply and demand mechanism, which controls the degree of housing quality in most environments, is rarely in favor of the consumer (higher quality at a reasonable price) since the supply normally lags far behind the demand. In the northern environment, where the influx of people comes in spurts dependent on the development of resources, the demand for housing is greater than the supply most of the time. An extreme example is the Alaska oil pipeline development which brought thousands of people to the North creating such a high demand on housing that the prices skyrocketed while the quality of housing was kept to an absolute minimum in order to maximize profits. The supply and demand method of controlling quality has not had beneficial effects for the user/buyer in the developing areas of the north.

The only mechanism which potentially "improves" housing quality (at a detail level) is the mortgage loan process in which the banks or lending institutions want to see a typical, familiar house design, a wall section, and heat loss data in order to make sure their investment will last and that it is marketable. While this mechanism helps to make sure the house has proper insulation and a vapor barrier, it also restricts any new or innovative ideas which may respond better to the climatic conditions if they resulted in housing which did not fall into their image of a "marketable" house.5

Guidelines/Controls

Any attempt to set up guidelines or controls regarding housing or environmental quality which responds well to the northern environment would probably meet with disapproval from the people the
controls would be trying to protect. Many of those living in the North are there to be free from the restrictions and regulations found in the more southern urban areas. This "frontiersman" attitude runs high among northern inhabitants and they generally do not want regulations which restrict their freedom especially when it applies to their home environment.

A study in a more remote area, Inuvik, N.W.T., reinforces the presence of this "frontiersman" attitude:

"About half of all civilians said that they were lured northward, wholly or in part, by the desire for adventure, travel, new experience, or the excitement of "pioneering". Indeed, if to these we add the people who spoke of the North's recreational attractions (notably hunting and fishing) and of the wish to escape city life, then it can be said that more than two-thirds of civilians in the sample were motivated, at least in part, by a desire to escape a routine existence in the South."  

Due to the problems confronting northern housing, the best method to approach them would be to disseminate information regarding building responses for the harsh and variable sub-arctic climatic factors to the users, buyers, and builders of housing. People can then better assess the quality of housing in the sub-arctic north establishing their own form of northern housing which reflects their priorities for climatic factors or opposing socio-cultural factors.
1.1.2 Existing Urban/Suburban Environments

How have the major Alaskan cities developed and what is their present form? The two largest cities of Anchorage (around 170,000 population in the area) and Fairbanks (around 70,000 population in the area) are little different from any other U.S. city in most respects, yet Fairbanks (65 north latitude) has a continental sub-arctic climate and Anchorage (61 north latitude) has a somewhat milder transitional sub-arctic climate.

"Anchorage was founded as the construction headquarters and survey camp for the building of the Alaska Railroad in 1914. Before World War II the population of the town was about 3,700, but with the advent of the army and air force, and the tremendous construction activity contingent upon defense, the population soared. Population growth has continued to accelerate with development of the Cook Inlet oil basin. Anchorage is a supply center for the new oil industry on the North Slope, as well as Cook Inlet. Many large oil companies maintain regional offices here, as do subsidiary organizations contributing to the industry.

E. T. Barnette erected the first building in Fairbanks, a log cabin cache for trade goods, in August, 1901. When he was unable to proceed beyond Bates Rapids in the Tanana River he turned back and cached his gear on the Chena. Before Barnette could build a more powerful boat with which to get his goods past the rapids, Felix Pedro found gold and staked claims on what were shortly named Pedro Creek and Cleary Creek. This was on July 22, 1902, and the ensuing stampede of prospectors into the area assured the growth of the new community. In 1906, with a population of 8,000, the production of gold in the Fairbanks district was valued at more than $9 million.

Fairbanks today is a center of trade and transportation far beyond that which is superficially indicated by population figures. It is the second largest population center in the state. The Steese, Richardson, Elliot, Alaska and Anchorage-Fairbanks Highways converge at Fairbanks; the Alaska Railroad extends from Fairbanks to tidewater at Anchorage and Seward; Intercontinental planes as well as intra-Alaska aircraft use the modern International Airport."
Housing in these cities initially consisted of log cabins clustered around a "downtown" near the river where goods were shipped by steamboats and paddlewheelers (Chena River in Fairbanks). Connection by road was not until World War II when the army built the Alaska Highway.

In the 1950's and 1960's, the areas around the towns began developing with subdivisions springing up in various locations. These housing areas are much like any other housing subdivision in other U.S. cities. A look at the Fairbanks map (page 13) one can see the subdivisions of Hamilton Acres, Aurora, and Arctic Park with their neatly laid out north/south, east/west street grid with the majority of tract houses situated along the east/west streets.

Downtown Anchorage is also on this grid pattern with the city's larger buildings now facing large one-way, east/west streets. The housing subdivisions have developed at various spots farther and farther from the city center making auto transportation a necessity and public transport unfeasible due to the dispersion of the population.

At present Fairbanks has one bus (public transport system) which travels from downtown out to the University (4 miles) along College Road. This makes it necessary for most people who need to go downtown or to shopping areas to drive their own vehicles. When it is very cold people often leave their autos idling so the car will not get cold while they do their shopping or other business. During the periods of cold temperature inversions, the air stagnates and the carbon monoxide reaches levels higher than nearly any other American city.

As these conditions indicate, the existing urban areas have not been planned for the northern environment in which they are situated. While solutions are being refined at the detail level, little is being done at higher planning levels which have a direct impact on the habitability of the housing and surrounding environment.
1.1.3 The Willow Site: The New Capital City of Alaska

This thesis focuses on a particular site which is designated for the future development of a new town, the new Alaska State Capital. Climatic planning at all design levels has particular importance in this case since there is no existing urban area which would predetermine the housing design potential at the higher planning levels (see figure 1.9).

Background on this particular site shows that in 1976 the people of Alaska voted to have the State Capital moved from its present location in Juneau, in southeastern Alaska, to an undeveloped site 40 miles north of Anchorage. The new location, the Willow Site, is on the east side of the lower Susitna River Valley. This location, approximately 62 north latitude and 150 west longitude, lies on the south side of the Alaska Range and to the southwest of the Talkeetna Mountains. The Alaska Railroad and the Anchorage-Fairbanks Highway are within close proximity to the site. 8

While the housing design responses developed by this study could be utilized in many cold climate areas with little or no modification, the application of the design responses (chapter 4) is focused towards optimal energetic responses to the climatic and site conditions present at the Willow Site. Other settlements in the world near this same latitude include: Yellowknife, N.W.T.; Frederikshaab, Greenland; Sundsvall, Sweden; Petrozavodsk and Yakutsk, Russia.

The new town at Willow is scheduled to have state employees begin moving in by 1980 and is expected to have a population of 25,000 by 1990. Housing costs are expected to be nearly 35% of the total cumulative cost of the new town by the year 1990. 9 The housing type mix was projected at 60% single family houses (40% @ 4 units/acre and 20% @ 9 units/acre), 30% multifamily (2 or more connected units), and 10%
mobile homes making a total of 4605 dwelling units by 1990.\textsuperscript{10} This estimate was supposedly based on historical data on comparative Alaska communities. The figures published in the Alaska Statewide Housing Study in 1971, show quite a different mix of housing types:\textsuperscript{11}

<table>
<thead>
<tr>
<th></th>
<th>1 Unit</th>
<th>2 or more units</th>
<th>Mobile Homes</th>
<th>Total Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nation</td>
<td>69.4%</td>
<td>27.9%</td>
<td>2.8%</td>
<td>67,607,842</td>
</tr>
<tr>
<td>State</td>
<td>52.5%</td>
<td>37.5%</td>
<td>10.1%</td>
<td>88,343</td>
</tr>
<tr>
<td>Anchorage</td>
<td>42.4%</td>
<td>45.8%</td>
<td>11.7%</td>
<td>37,622</td>
</tr>
<tr>
<td>Fairbanks</td>
<td>39.3%</td>
<td>52.8%</td>
<td>7.9%</td>
<td>12,488</td>
</tr>
<tr>
<td>Juneau</td>
<td>49.4%</td>
<td>40.5%</td>
<td>10.0%</td>
<td>4,519</td>
</tr>
</tbody>
</table>

Since this study in 1971 there has been a great deal of housing construction due primarily to the oil pipeline construction. There has been a marked increase in the amount of compact housing units built (2 or more units) which could shift the above figures even higher in that category. With this in mind, a more reasonable housing mix projection for the new Capital would have 40% single family houses, 50% multiple/compact housing, and 10% mobile homes. With this in mind, this thesis presents building responses to the climatic factors which could be applied to both single family houses and multiple/compact housing.
1.2 GOALS

- To enhance the quality/habitability of northern housing through better responses to the sub-arctic environmental factors (climatic and site factors).
- To maximize energy efficiency by optimizing control and use of the climatic factors.
- To develop housing design responses for the sub-arctic environment with application to a specific site.
- To provide a housing design/evaluation base for user education and participation.

1.3 SCOPE

Within the context of the total design process, the area of investigation is limited to the climatic factors: solar radiation, temperature, precipitation, wind, and special climatic conditions (humidity/moisture potential, blowing snow, permafrost, and active layer/frost heave); as well as the specific site factors: topography, geology/soils, hydrology, and vegetation. The functional requirements which determine interior space arrangements of housing designs are dealt with only as they relate to the climatic/site factors (figure 1.8).

The first part, chapter 2, deals with the climate, comparing the different climatic zones within the State of Alaska (arctic, continental, transitional, and maritime), as well as comparing the sub-arctic transitional zone with more familiar "cold climate" zones in the "lower 48" and southern Canada.

The purpose of this introductory part of the thesis is to point out the major regional differences of the climatic factors which influence our way of life and performance of our buildings.

Both social and physical problems are intensified by the sub-arctic climatic conditions. Such social
implications as "cabin fever" and intensified interaction in confined spaces can either be relieved or intensified by the built environment. The social implications related to the northern environment are important and more quantitative studies should be done in this field. This type of study is not within the scope of this thesis. It is hoped that to some extent the housing users/buyers can identify their own social needs with regard to their living environment and make adjustments accordingly, given the control and flexibility needed.

The second part, chapter 3, aims at optimizing the control and use of the climatic stressors and resources. This part presents the climatic implications on building and illustrates the design responses to the climatic factors. These design responses are treated at four planning levels: planning level 1, site layout/circulation patterns; planning level 2, building size, shape, and orientation; planning level 3, activity/space arrangement; and planning level 4, detailing of the building fabric (figure 1.9). Proper environmental design at the higher planning levels help to lessen the impact of the climatic factors which must be dealt with at the lower planning levels (building fabric). This part could be used as a program for design/evaluation for the climate, which can be applicable to much of the northern environment.

The third part, chapter 4, evaluates the implications and responses under the climatic factors presented in chapter 3 and states a preference of design tradeoffs at the higher planning levels as they pertain to a particular site, the Willow Site.
<table>
<thead>
<tr>
<th>Parameters/Responses</th>
<th>Other Parameters Presented To Varying Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope:</strong></td>
<td></td>
</tr>
<tr>
<td>Physical Factors</td>
<td></td>
</tr>
<tr>
<td>Climate</td>
<td></td>
</tr>
<tr>
<td>Sun</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td></td>
</tr>
<tr>
<td>Temp.</td>
<td></td>
</tr>
<tr>
<td>Precip.</td>
<td></td>
</tr>
<tr>
<td>Geology</td>
<td></td>
</tr>
<tr>
<td>Soils</td>
<td></td>
</tr>
<tr>
<td>Topography</td>
<td></td>
</tr>
<tr>
<td>Vegetation</td>
<td></td>
</tr>
<tr>
<td>Hydrology</td>
<td></td>
</tr>
<tr>
<td>Social/psychological Factors</td>
<td></td>
</tr>
<tr>
<td>Social Structure</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td></td>
</tr>
<tr>
<td>Stratification</td>
<td></td>
</tr>
<tr>
<td>Perception of Environment By People</td>
<td></td>
</tr>
<tr>
<td>Legal/Political</td>
<td></td>
</tr>
<tr>
<td>Codes</td>
<td></td>
</tr>
<tr>
<td>Zoning</td>
<td></td>
</tr>
<tr>
<td>Cultural Patterns</td>
<td></td>
</tr>
<tr>
<td>Historical</td>
<td></td>
</tr>
<tr>
<td>Colonial</td>
<td></td>
</tr>
<tr>
<td>Biological Needs</td>
<td></td>
</tr>
<tr>
<td>Functional Factors</td>
<td></td>
</tr>
<tr>
<td>Requirements For Varied Uses</td>
<td></td>
</tr>
<tr>
<td>Circulation</td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td></td>
</tr>
<tr>
<td>Regional</td>
<td></td>
</tr>
<tr>
<td>Mode</td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>Sewer</td>
<td></td>
</tr>
<tr>
<td>Elect. etc.</td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td></td>
</tr>
<tr>
<td>Schools</td>
<td></td>
</tr>
<tr>
<td>Hospitals</td>
<td></td>
</tr>
<tr>
<td>Etc.</td>
<td></td>
</tr>
<tr>
<td>Economic Factors</td>
<td></td>
</tr>
<tr>
<td>Market Analysis/Investment</td>
<td></td>
</tr>
<tr>
<td>Financing</td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td></td>
</tr>
<tr>
<td>State</td>
<td></td>
</tr>
<tr>
<td>Federal</td>
<td></td>
</tr>
<tr>
<td>Life Cycle Costs</td>
<td></td>
</tr>
<tr>
<td>Construction Costs</td>
<td></td>
</tr>
<tr>
<td>Building Costs</td>
<td></td>
</tr>
<tr>
<td>Coord. of Technical Services</td>
<td></td>
</tr>
<tr>
<td>Satisfaction of Functional Requirements</td>
<td></td>
</tr>
<tr>
<td>Design/Reserves</td>
<td></td>
</tr>
<tr>
<td>Site Selection</td>
<td></td>
</tr>
<tr>
<td>Site Layout</td>
<td></td>
</tr>
<tr>
<td>Building Orientations</td>
<td></td>
</tr>
<tr>
<td>Size, Shape, Location</td>
<td></td>
</tr>
<tr>
<td>Technical Services</td>
<td></td>
</tr>
<tr>
<td>Satisfaction of Functional Requirements</td>
<td></td>
</tr>
<tr>
<td><strong>Technical Application</strong></td>
<td></td>
</tr>
<tr>
<td>Structural Systems</td>
<td></td>
</tr>
<tr>
<td>Mech/Elec. Systems</td>
<td></td>
</tr>
<tr>
<td>Material/Construction Systems</td>
<td></td>
</tr>
<tr>
<td>Special Systems</td>
<td></td>
</tr>
<tr>
<td>Acoustic/Landscape</td>
<td></td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1.8**
### Planning Level 1

**Scope:**
- Layout of the main vehicle and pedestrian circulation patterns and independent buildings within the surrounding environment.

**Impact:**
- Problems associated with auto transportation and micro-climate problems created with solar shadowing and wind impact.

**Level of Control:**
- City Planning and Development Boards, developers of subdivisions, and concerned citizen's committees.

**Example of Impact:**
- The large Polaris building on the south side of 1st ave. (east-west street) in Fairbanks shadows both sides of the street creating a dark, cold micro-climate.

### Planning Level 2

**Scope:**
- Determination of the individual building's size, shape, and orientation.

**Impact:**
- Increase or decrease in energy efficiency, sunlight distribution, solar shadowing, and wind impact.

**Level of Control:**
- City Planning Approval Boards, contractors, architects, citizen's groups, and individual buyers/builders.

**Example of Impact:**
- The use of long, low ranch style houses which have a high potential for heat loss and north side shadowing.

### Planning Level 3

**Scope:**
- The arrangement of spaces and activities within and around the housing unit as they relate to the climatic factors.

**Impact:**
- Increase or decrease in the habitability and comfort levels of certain spaces and activities.

**Level of Control:**
- Designers, builders, and users/builders to some extent depending on flexibility within and around the housing unit.

**Example of Impact:**
- The misplacement of interior spaces or exterior activity spaces to the north side where seasonal use is limited due to a lack of solar radiation.

### Planning Level 4

**Scope:**
- The detailing and selection of the building fabric materials.

**Impact:**
- Increase or decrease the longevity of the structure and the costs of operation and maintenance.

**Level of Control:**
- Designers, builders, and the individual users/buyers depending on the amount of input when the house is designed and built.

**Example of Impact:**
- Poorly insulated houses without proper vapor barriers and with large window areas will have material deterioration along with high operating costs.

*Figure 1.9*
1.4 METHODOLOGY

The methodology employed in this thesis involves the evaluation of literature, published and unpublished, as well as evaluation of my personal living and design experience in the North.

The literature search included: material available on the U.B.C. campus; material received from other schools (Univ. of Washington and Univ. of Manitoba); and solicited material from various sources (Ralph Erskine's firm in Sweden, CRREL in Hanover, New Hampshire, Canadian National Research Council in Ottawa, and the National Weather Service (U.S.) in North Carolina).

The personal experience included: architectural design work with Gray, Rogers Myers, & Morgan; Ellerbe Architects; and G.D.M. and Associates all in Fairbanks, Alaska, from 1972 to 1975; completion of Arctic Engineering 603 and 604 at the university of Alaska from Dr. Eb Rice; and personal conversations with northern inhabitants along with my own experiences.

1.5 APPLICATION

• To make the users and builders more aware of design responses which respond better to the climate.

• User participation in upgrading the quality of housing through demand on contractor built housing and self-help building programs.

• Establish a greater energy consciousness in housing design - a closer look at the operation and maintenance costs when assessing quality in housing.

• Use by all income levels in evaluating housing: single family housing, compact housing, co-op housing, self-help housing, and trailer park/mobile home selection.
1.6 IMPLEMENTATION

- Weekly or biweekly newspaper articles showing housing which responds well within the northern environment.
- University or Alaska evening course for home builders/buyers.
- University Cooperative Extension Service publications, individual pamphlets for building in Alaska.
- Articles for The Northern Engineer and other interested publications
- Application to my own design work in the North.

1.7 DEFINITIONS

A. Housing Quality:
Level one - as it relates to satisfying basic needs: adequate space, shelter/protection from the elements, and ability to reach work, schools, and services.
Level two - as it relates to habitability and comfort: provides a comfortable living environment with regard to sunlight, daylight, temperature, and humidity while expending the least amount of energy to achieve these.
Level three - as it relates to costs of operation and maintenance: energy efficient design with the ability to withstand the seasonal climatic stresses as well as normal abuse with adequate detailing to minimize material deterioration and malfunctioning.

B. Optimal Design for Climate:
This relates to the energy balance between potential incoming natural energy and the outflow of energy (heat) within the housing unit (artificial and natural).
C. Planning Levels

These are established in this thesis from level 1 (highest) to level 4 (lowest) since decisions made at the higher planning levels have an effect on the options at the lower planning levels. For example, if a large, tall building is sited to the south of a smaller building (planning level 1), then this may effect the smaller building's orientation, shape, activity space locations, and fabric detailing regarding solar radiation.

D. Physical Factors:

These refer to both the climatic factors and site factors.

E. Climatic Factors:

These refer to climate and climatic combinations of solar radiation (light and heat), temperature, precipitation, wind, and humidity/moisture potential.

F. Site Factors:

These refer to the naturally occurring site conditions with regard to topography, geology/soils, hydrology, and vegetation.

G. Design Responses:

These refer to the solutions which can be incorporated into the built environment to make use of or minimize the stress from the physical factors.
REFERENCES


5. Problems were encountered with getting housing loans for several houses which had exceptionally low heat loss characteristics but appeared unconventional in appearance (not the typical ranch style house).


8. Capital Site Selection Committee, "The Selection of a Capital Site Will Soon Be In Your Hands," Supplement to all Alaskan newspapers, summer 1976

9. Ibid.


CHAPTER 2

CLIMATIC COMPARISONS

2.1 INTRODUCTION

2.2 SOLAR RADIATION
  2.2.1 Objective/Background
  2.2.2 Apparent Sunpath (Altitude and Azimuth)
  2.2.3 Albedo
  2.2.4 Cloud Cover
  2.2.5 Building Implications

2.3 TEMPERATURE
  2.3.1 Objective
  2.3.2 Duration of Cold Extremes
  2.3.3 Seasonal Temperature Differences
  2.3.4 Diurnal Temperature Variations
  2.3.5 Building Implications

2.4 PRECIPITATION
  2.4.1 Objective
  2.4.2 Normal Yearly Precipitation
  2.4.3 Extreme Precipitation Amounts Over Short Periods
  2.4.4 Snow Cover Amounts and Duration
  2.4.5 Building Implications

2.5 WIND
  2.5.1 Objective
  2.5.2 Mean Winter Wind Speed and Direction
  2.5.3 Mean Summer Wind Speed and Direction
  2.5.4 Maximum Wind Speeds and Directions
  2.5.5 Katabatic Wind
  2.5.6 Building Implications

2.6 SPECIAL CLIMATIC CONDITIONS
  2.6.1 Objective
  2.6.2 Humidity/Moisture Potential
  2.6.3 Blowing Snow
  2.6.4 Permafrost
  2.6.5 Active Layer/Frost Heave

2.7 SUMMARY
1.1 INTRODUCTION

Since most of the people living in the northern urban areas relate to more southern forms of housing with comforts and conveniences as well as planning patterns which were developed for temperate climatic areas, it is first necessary to point out the differences in the climatic factors which influence the performance of buildings as well as the way of life in the North. The objective of this chapter is to indicate the pertinent climatic differences between "northern zones" within Alaska as well as differences between these zones and more southern "cold zones".

There are four major climatic zones within the State of Alaska: the arctic zone, the northern most region bordering the Arctic Ocean; the continental zone, that area encompassing the interior of the state; the transitional zone, northern areas under the influence of large bodies of water giving the zone both continental and maritime influences; and the maritime zone, primarily southeastern Alaska yet encompassing much of the region bordering on the Gulf of Alaska.

First, the differences in these northern zones is explained, then the climatic differences are compared with those of lower latitudes in which people are more familiar.

In order to use existing climatological data, settlements with recorded data have been picked to represent the different climatic zones. The comparative northern zones and representative settlements in Alaska are:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Settlement</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Arctic Zone</td>
<td>Barrow, Ak.</td>
<td>71° 18' N. Lat.</td>
</tr>
<tr>
<td>The Continental Zone</td>
<td>Fairbanks, Ak.</td>
<td>64° 49'</td>
</tr>
<tr>
<td>The Transitional Zone</td>
<td>Anchorage, Ak.</td>
<td>61° 10'</td>
</tr>
<tr>
<td></td>
<td>Talkeetna, Ak.</td>
<td>62° 18'</td>
</tr>
<tr>
<td>The Maritime Zone</td>
<td>Juneau, Ak.</td>
<td>58° 22'</td>
</tr>
</tbody>
</table>
The comparative southern zones and representative settlements are:

The Continental Zone  Minneapolis, Minn.  44° 53' N. Lat.
The Maritime Zone  Vancouver, B. C.  49° 11' N. Lat.

With the exception of Barrow and Talkeetna, the cities are well known urban centers within Alaska, Minnesota (north-central U.S.) and British Columbia (Western Canada). Talkeetna is a small settlement in the Susitna Valley, 80 air miles north of Anchorage, Alaska's largest city, and 44m. north of the location for the Alaska State Capital city at Willow.

These areas are compared with regard to:

1. Solar Radiation
2. Temperature
3. Precipitation
4. Wind
5. Special Climatic Conditions
   a. Humidity/Moisture Potential
   b. Blowing Snow
   c. Permafrost
   d. Active Layer/Frost Heave

The implications of these climatic conditions on building design will be mentioned in this chapter with the next chapter elaborating on the design responses (solutions).
2.2 SOLAR RADIATION

2.2.1 Objective/Background

This section shows the extent to which solar radiation characteristics change with latitude change (solar angles and azimuths) as well as climatic zone types (duration of cloud cover), and the implications these differences have on the built environment.

Differences in the apparent sun path are discussed in terms of the latitude change instead of climatic zones since the latitude determines these differences. The effects of cloud cover, % of possible sunshine, and albedo are discussed in terms of the climatic zones.

Since the latitude change within Alaska ranges from close to 51° in the Aleutian Islands and 55° in southeastern Alaska to over 71° at Barrow (20° latitude difference), it's important to know the characteristics of the sun for each particular area where development occurs. The 20° latitude change would be comparable to the distance from just north of San Francisco in northern California to the Yukon border. Even the more southern portions of Alaska, i.e., Ketchikan at 55° are close to 10° further north than Minneapolis, Minn. (45° North latitude).

2.2.2 Apparent Sun Path (Altitude and Azimuth)

Lower midday sun angles and high seasonal variation in solar azimuth travel increase with an increase in latitude. Figure 2.5 shows the midday sun angle for various latitudes on December 21st and June 21st, the solstices, and March 21st and September 21st, the equinoxes. Also, the angle is shown for east and west orientations on June 21st at 6am and 6pm. The sun at Barrow reaches only 43° altitude at noon on the longest day, yet the sun is 22° above the horizon when coming from east and west (6am and 6pm), and 32° at midnight from the north. The Minneapolis sun, 45° N. Lat., has a noon altitude of 68° on June 21st, 16° at 6am and 6pm, and no midnight sun.
The lower sun angles in higher latitudes cause a reduction in the sun's radiation intensity. The reduction of radiation due to the earth's atmosphere depends on the composition of the atmosphere and the length of atmospheric path traversed.

From the graph, which relates the atmospheric mass through which the solar radiation passes with the sun angle, the atmospheric mass begins having a marked effect when the sun angle drops below 20°-25°. From 20° sun angle to 10° sun angle the atmospheric mass doubles and from 10° to 5° sun angle the mass doubles again, so the solar intensity drops off quite rapidly when the sun angle drops below 20°.

Another factor effecting solar intensity is the spread of the solar radiation over a greater distance as the sun's rays approach the poles.

This factor is more important in heating surfaces parallel to the earth's surface (horizontal) such as in agriculture. Buildings counter this factor with building surfaces that are more perpendicular to the sun's rays.
During the winter season the sun's altitude is very low, with Barrow getting no sun for over two months, Fairbanks with a $1\frac{1}{2}^\circ$ angle at noon on the shortest day compared to $21\frac{1}{2}^\circ$ angle for Minneapolis. This winter sun hits and penetrates buildings in the more northern latitudes only from the south due to the short solar azimuth travel at the winter solstice. In more southern latitudes the sun penetrates more from the east and west as well as from the south, see figure 2.6.

From March 21st to September 21st, higher latitudes experience more potential sunlight hours than lower latitudes due to the large solar azimuth travel in summer. North of the Arctic Circle ($66\frac{1}{2}^\circ$) the seasonal sunlight change is from 0 hours of winter sunlight to 24 hours of sunlight in summer while in the northern U.S. and southern Canada the range is from a low of 8 to 9 hours in December to around 16 hours in June, a change of roughly 8 hours over the year as compared to 24 hours, see figure 2.7.

The yearly distribution of solar energy becomes more lopsided the further north one goes. The longer summer days give the potential for large amounts of solar heat gain while the short winter days gain little solar heat while the long nights radiate large amounts of heat out to the atmosphere.

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Summer % (Mar. 21 to Sept. 21)</th>
<th>Winter % (Sept. 21 to Mar. 21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55°</td>
<td>63</td>
<td>37</td>
</tr>
<tr>
<td>60°</td>
<td>66</td>
<td>34</td>
</tr>
<tr>
<td>65°</td>
<td>71</td>
<td>29</td>
</tr>
<tr>
<td>70°</td>
<td>79</td>
<td>21</td>
</tr>
</tbody>
</table>
WINTER & SUMMER SOLAR AZIMUTH TRAVEL COMPARISON (DISTANCE SUN TRAVELS ABOVE HORIZON)

FIGURE 2.6
2.2.3 Albedo

In the winter and spring when the ground is covered with snow, the sunlight can go through multiple reflections between snow and cloud cover giving fairly high intensities of diffused light. So while the sun may be closer to the horizon (low altitude), with the aid of snow and clouds it still has the potential of supplying a fair amount of reflected and diffuse light during the short days of winter.

2.2.4 Cloud Cover

In addition to the effect of latitude change, weather systems and cloud cover effect the amount of sunlight available to any particular area. The cloud cover is more a function of the areas location in relation to oceans and predominant weather zones, ie, climatic zones. The arctic zone is the driest of all northern climatic regions yet still experiences a good deal of high cloud cover. The continental zone has less cloud cover and more sunlight than all other regions in Alaska. The transitional zone, being a combination of the continental and maritime zones normally receives more cloud cover than the continental but less than the maritime regions. The maritime zone receives the most cloud cover with the lowest percent of possible sunlight.
2.2.5 Building Implications

The lack of winter sunlight effects building design mainly with regard to the psychological importance of maximizing winter sunlight as well as the need for more artificial light during the longer winter period. In building design it's less important to try to optimize the mid-winter solar heat gain than it is to minimize the loss of heat radiating out to the atmosphere.

The lower solar altitude causes greater solar shadowing potential in winter especially when the sun comes only from the south.

During the summer months, the longer azimuth travel and lower sun angles produce longer periods of possible heat gain on south, east, and west vertical surfaces since the sun rays are closer to perpendicular to these surfaces. The lower angles also permit the sun's rays to penetrate inside a building further through the openings in vertical surfaces. It may become necessary to protect against unwanted solar penetration due to low angle sunlight coming from the northwest, north, and northeast.

The high albedo during winter and spring can create glare problems. The increased glare potential can be bothersome especially during the spring when there are more sunlight hours and the snow is still on the ground reflecting the sunlight.

Cloud cover causes varying degrees of diffuse solar radiation which yields less solar heat gain to the building surfaces than direct sunlight during clear sky conditions. So areas with a lot of cloud cover such as Juneau in the maritime region would normally receive much less solar heat gain than the Alaskan interior during spring and summer.
2.3 TEMPERATURE

2.3.1 Objective

This section describes the differing climatic zones by the length of time that cold temperatures exist, the seasonal temperature differences, as well as diurnal variations. The implications of these on the built environment are discussed at the end of this section.

2.3.2 Duration of Cold Extremes

A look at the four major Alaskan climatic zones on figure 2.9 shows the average yearly temperature range from 9.3°F at Barrow to 40.3°F at Juneau. Anchorage and Talkeetna average 32°F to 34°F, about 8°F warmer than Fairbanks on a yearly average.7

Figure 2.8 shows the number of days per month that the temperature is below 0°F. Fairbanks and Talkeetna have 0°F temperatures from October through April (7 months) while Juneau experiences 0°F temperatures from December through March (4 months). In January, Fairbanks averages 29 days below 0°F, Talkeetna 16 days, and Juneau 5 days.8

The heating ° days (base temperature of 65°F) show a comparison of heat required over the year for each area: 9 Minneapolis 8,159 Degree Days Juneau 9,155 " " Anchorage 10,911 " " Talkeetna 11,708 " " Fairbanks 14,344 " " Barrow 20,265 " "

While the continental zones (Fairbanks and Minneapolis) both experience cold temperatures, the duration of the cold in the north causes a 76% higher heating requirement over the year for Fairbanks. The transitional zone areas require about 40% more heat than the more southern continental zone.
<table>
<thead>
<tr>
<th>110°</th>
<th>151°</th>
<th>139°</th>
<th>113°</th>
<th>108°</th>
<th>92°</th>
<th>135°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAR, FAIR, TALK, ANCH, JUNEAU, VAN, MINN.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVERAGE YEARLY TEMPERATURES OF (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12°C</td>
<td>13°C</td>
<td>14°C</td>
<td>15°C</td>
<td>16°C</td>
<td>17°C</td>
<td>18°C</td>
</tr>
<tr>
<td>-3°C</td>
<td>-2°C</td>
<td>-1°C</td>
<td>0°C</td>
<td>1°C</td>
<td>2°C</td>
<td>3°C</td>
</tr>
<tr>
<td>4°C</td>
<td>5°C</td>
<td>6°C</td>
<td>7°C</td>
<td>8°C</td>
<td>9°C</td>
<td>10°C</td>
</tr>
</tbody>
</table>

**Figure 2.8**

**Figure 2.9**

**NUMBER OF DAYS PER MONTH IN TEMP BELOW 0°F**

**FAIRBANKS CONTINENTAL NORTH**

**TALKEETNA TRANSITIONAL**

**ANCHORAGE TRANSITIONAL**

**MINNEAPOLIS CONTINENTAL SOUTH**

**JUNEAU MARITIME NORTH**
2.3.3 Seasonal Temperature Differences - average and extreme

The average yearly variations in temperature from winter to summer are:

- Minneapolis: 12.2°F to 71.9°F (59.7°F)
- Anchorage: 11.8°F to 57.9°F (46.1°F)
- Talkeetna: 9.0°F to 57.9°F (48.9°F)
- Fairbanks: -11.9°F to 60.7°F (72.6°F)

The northern continental zone experiences the greatest variation in temperature making it more difficult to design for both summer and winter conditions.

Thirty year seasonal extreme temperature differences range from 157°F at Fairbanks, 108°F at Juneau, to 92°F at Vancouver. The range of temperature extremes do not vary greatly between continental zones. Fairbanks has extreme temperature differences only 14% greater than that of Minneapolis (157°F vs 135°F) with the summer highs and winter lows both lower as shown on figure 2.10.

Temperature extremes are more pronounced in the continental zones than in the maritime zones. Each specific zone, ie, continental, has lower low extreme temperatures and lower high temperatures than the same climatic zone in a lower latitude.
2.3.4 Diurnal Temperature Variations

The diurnal temperature variations (nighttime low temperature versus daytime high temperature) are greatest in the continental zones (Fairbanks, with up to a 15 deg. F variation and Minneapolis with up to a 21 deg. F variation) becoming less the more the temperatures are influenced by large bodies of water such as in the maritime regions. Anchorage's diurnal variations are normally around 15 deg. F due to the influence of Cook Inlet. While moving up the Susitna Valley, Talkeetna's diurnal temperature variations range from 17 deg. F to 25 deg. F, see figures 2.11 and 2.12.
MONTHLY TEMPERATURE/RELATIVE HUMIDITY DATA

62° N. LAT. (TALKEETA)

FIGURE 2.12
During winter months the diurnal temperature change is negligible since the cloud cover controls the temperature variations more than the low solar radiation.

The diurnal variations in the northern zones are not balanced around a temperature which is considered comfortable such as in a warmer climate where the range may be between $50^\circ F$ and $100^\circ F$. The northern continental and transitional zones normally have both high and low temperatures below the $65^\circ F$ temperature for most of the year requiring supplemental heat to reach comfortable temperatures.

<table>
<thead>
<tr>
<th>Normal Daily Maximum above $65^\circ F$</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>Sept.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchorage</td>
<td>65.6°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Talkeetna</td>
<td>67.7°</td>
<td>65.7°</td>
<td>67.5°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fairbanks</td>
<td>70.7°</td>
<td>71.8°</td>
<td>65.8°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minneapolis</td>
<td>67.9°</td>
<td>77.1°</td>
<td>82.4°</td>
<td>80.8°</td>
<td>70.7°</td>
</tr>
</tbody>
</table>

2.3.5 Building Implications

The most important building implications relate to the duration of the extreme cold temperatures.

First, the duration of the extreme cold temperatures effects the functioning of an urban environment based on our current modes of transportation (autos, airplanes). The automobile experiences many problems involving starting, operation, and maintenance during the cold winters. In addition to this, the autos, trucks, buses, and airplanes produce ice fog which can accumulate over a period of a week or two reducing visibility to a minimum and occasionally bringing air traffic to a halt (most significant in the Interior where clear skys and minimal wind combine to produce the extreme cold temperatures).

Second, the cold temperatures produce the frozen ground conditions (permafrost) as well as trigger the mechanism of frost heave in the soil. These conditions
can have adverse effects on the foundation stability of structures.

Third, the amount of heating degree days has a direct effect on the cost of operation of any heated structure. Economically speaking it is most important to minimize the building heat loss to the cold exterior temperatures. This can be done in a number of ways which are outlined in chapter 3.

Fourth, the conduction of the cold temperatures into the building interior through "thermal bridges" or poorly insulated surfaces (windows) can cause a great many problems from frost build up in building materials to the freezing and frost accumulation on interior surfaces (windows, corners).
2.4 PRECIPITATION

2.4.1 Objective

The primary concern with precipitation is the total yearly amount of precipitation, extreme amounts in short periods, and the amount and duration of snow cover for the differing climatic regions. The intent in this section is to point out these differences and indicate the implications to the built environment.

2.4.2 Normal Yearly Precipitation

The maritime zone receives the greatest amount of precipitation of all Alaska zones as figure 2.13 shows; 55 inches for Juneau (as much as 188" per year in parts of southeastern Alaska's maritime region) while Barrow in the arctic zone barely receives 5" per year. The interior of Alaska is relatively dry with Fairbanks averaging 11" a year while on the south side of the Alaska Range, the weather system changes giving Talkeetna nearly 30" a year. Closer to Cook Inlet, the precipitation drops off to 15" a year for Anchorage.

![Mean Precipitation Totals Graph](image)

Yearly precipitation (inches) includes both rain and snow. The conversion from snow to precipitation is normally 10 to 1.
In the continental zones, Minneapolis gets more than twice as much precipitation as Fairbanks, mostly in the spring and summer. This difference may be due to the dryness caused by frozen conditions during a larger portion of the year in the northern continental zone.

2.4.3 Extreme precipitation Amounts Over Short Periods

<table>
<thead>
<tr>
<th>Area</th>
<th>Precipitation</th>
<th>Snow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchorage</td>
<td>1.66&quot; (Nov.)</td>
<td>16.4&quot; (Nov.)</td>
</tr>
<tr>
<td>Talkeetna</td>
<td>3.12&quot; (Sept.)</td>
<td>36.0&quot; (Feb.)</td>
</tr>
<tr>
<td>Fairbanks</td>
<td>3.42&quot; (Aug.)</td>
<td>20.1&quot; (Feb.)</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>4.12&quot; (July)</td>
<td>16.2&quot; (Nov.)</td>
</tr>
</tbody>
</table>

The greatest potential hazard occurs when the extreme rain or snow is much higher than the average causing excessive runoff erosion, flooding, and structural failure. As an example, the 3.42" 24 hour precipitation for Fairbanks helped cause the 1967 August flood which put the whole city under several feet of water. The 36" (3') of snow fall in 24 hours in Talkeetna could cause structural damage to roofs not designed to handle the heavy snow loads.

2.4.4 Snow Cover Amount and Duration

The length of time in which the ground is covered with snow varies from 6 1/2 months in Fairbanks to 3 months in Minneapolis, see figure 2.14. Once the snow falls in the fall in Alaska's arctic, continental, and transitional zones, it normally stays until the spring when the winter's accumulation melts away. In more southern regions such as Minneapolis, temperatures in the 40's occur in winter months causing snow to melt from time to time.

In the maritime zones, Juneau and Vancouver are close when it comes to total precipitation, see figure 2.13. Juneau's peak month is October while Vancouver's falls in December. The big difference between the two
is the presence of lower temperatures farther north causing much more snowfall as can be seen by Juneau's 107" versus Vancouver's 18" of snow per year. Juneau's snow will thaw, causing slush, during warm periods during the winter, later freezing into ice. This seldom occurs farther north in the transitional and continental zones due to the more constant colder winter temperatures.

More southern maritime regions experience less snowfall such as Vancouver's average of 18"/year which normally melts away in several days or a week after the storm, causing slush for short periods of time in the winter.

2.4.5 Building Implications

Building design implications for precipitation become most critical in the northern maritime region where problems are related to snow and ice.

Icy winter conditions make transportation, the direction and slope of roads and circulation systems, a major design factor in city planning and operation. The large accumulations of heavy, water saturated snow make snow protection, removal, and structural design of buildings more critical in the northern maritime region than in the other northern regions where the snow is light and dry and accumulation is less.

In the arctic region, the presence of blowing snow becomes a major design implication since the drifting potential can block access and cover portions of buildings, this is discussed in more detail in a later section.

In the northern transitional and continental regions it becomes more important to focus building design towards the use of snow's insulating qualities (more critical for warmth, fuel consumption, and the functioning of utilities).
Snowfall - Monthly Mean

Number of Months with Snow Cover on Ground
- Barrow: Sept - June, 7 1/2 months
- Fairbanks: Oct - mid April, 6 1/2 months
- Talkeetna: mid Oct - Mar, 5 1/2 months
- Anchorage: Nov - Mar, 5 months
- Juneau: Nov - May, 4 months
- Vancouver: several days in Dec & Jan
- Minneapolis: mid Dec - mid Mar, 3 months

Mean Yearly Snowfall & Max in 24 Hours

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean 24-Hr Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrow</td>
<td>35''</td>
</tr>
<tr>
<td>Fairbanks</td>
<td>20.1''</td>
</tr>
<tr>
<td>Talkeetna</td>
<td>32''</td>
</tr>
<tr>
<td>Anchorage</td>
<td>16.4''</td>
</tr>
<tr>
<td>Juneau</td>
<td>18.7''</td>
</tr>
<tr>
<td>Vancouver</td>
<td>17''</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>16.2''</td>
</tr>
</tbody>
</table>

Figure 2.14
2.5 WIND

2.5.1 Objective

The average wind speeds and directions for both winter and summer are important when trying to minimize wind chill, heat loss, and snow drifting. Extreme wind speeds and directions are important primarily in the structural design of the building. The areas with katabatic winds are important to know in order to avoid extreme cold temperatures. The figures 2.15, 2.16, and 2.17 compare the wind data from the differing climatic zones which help to show which regions have the greatest design implications for wind.

2.5.2 Mean Winter Wind Speed and Direction

In the Alaskan climatic zones, Fairbanks in the continental zone has the least amount of wind during the winter months (3.4 mph) with calm conditions 48% of the time, Anchorage and Talkeetna, under the influence of Cook Inlet, have at least 1.5 times the mean wind speed of Fairbanks (5.5 mph) with calm conditions 20% of the time. Juneau, being maritime, receives a higher constant wind throughout the year with a mean speed from November to February of 8.8 mph with calm conditions about 5% of the time. Barrow, in the arctic zone, has continual wind during the winter with calm conditions only 1% of the time, see figure 2.15.\textsuperscript{15}

The wind direction during these cold months remains nearly constant for each location. The direction itself depends on the topography of each particular area in combination with the air movement of the region. So a higher latitude or the type of climatic zone is not always a major determinant in wind direction, each individual area will have its own wind patterns which need to be known for effective building design for that area.

In the continental zones, Fairbanks and Minneapolis vary greatly in wind movement throughout the winter. Minneapolis (10.6 mph mean speed) is much more exposed to winter storms and the movement of air masses while
ALASKA
SCALE OF MILES
0 50 100 150 200 250
ONE INCH EQUALS APPROXIMATE MILES

Controlled Access Highways

Principal Through Highways

Other Through Highways

Connecting Highways

SURFACE WIND ROSES, JANUARY

% OF TIME WIND BLOW FROM THE COMPASS POINT OR WAS CALM

15 10 5

FIGURE 2.15
Fairbanks and the Alaska interior, due to persistent snow cover during the winter months, experience little heat gain since the white surface prevents absorption therefore creating little air movement.

The maritime regions are more subject to an east-west wind direction pattern, Juneau is sandwiched in between mountains running north and south which break up this pattern somewhat. Yet, during the cold months Juneau receives most of its wind from the east - southeast with the occasional "Taku Wind" coming from the north. Similarly Vancouver's winter winds blow from the east and southeast with occasional strong blows from the west or northwest.

2.5.3 Mean Summer Wind Speed and Direction

In the arctic region, Barrow's wind speed increases slightly during summer with calm conditions only 2% of the time while the direction remains similar to that during winter. Fairbanks has slightly increased wind speeds with calm conditions dropping to 12% of the time, the predominant direction is from the southwest, 180° from the winter wind. The Cook Inlet/ Susitna Valley area has summer wind similar in speed to winter wind with calm conditions 10% of the time and a predominant direction opposite that of the winter wind. Southeastern Alaska (Juneau) has a slight drop in summer wind speed and a change in direction from east-southeast to north (+100 shift), see figure 2.16.

2.5.4 Maximum Wind Speeds and Directions

Juneau gets its winter "Taku Winds", strong northerly winds most often caused by the flow of cold air from northwestern Canada through nearby mountain passes and over the Juneau Ice Field. Anchorage gets strong, gusty, north winds which occur, on the average, once or twice during the winter which can cause drifting and packing of snow cover. Talkeetna experiences relatively light north-northeast winter winds. Fairbanks normally has only light winds in the winter months, while Barrow receives a constant coastal wind, see figure 2.17.
Figure 2.16
Figure 2.17

Mean Wind Speed (mph) & Prevailing Directions

<table>
<thead>
<tr>
<th>AREA</th>
<th>NOV</th>
<th>DEC</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairbanks</td>
<td>WSW</td>
<td>WSW</td>
<td>W</td>
<td>W</td>
<td>SW</td>
</tr>
<tr>
<td>Talkeetna</td>
<td>NNE</td>
<td>NE</td>
<td>NNE</td>
<td>NNE</td>
<td>WNE</td>
</tr>
<tr>
<td>Anchorage</td>
<td>NW</td>
<td>NE</td>
<td>NNE</td>
<td>N</td>
<td>UNW</td>
</tr>
<tr>
<td>Juneau</td>
<td>ESE</td>
<td>ESE</td>
<td>ESE</td>
<td>SE</td>
<td>ESE</td>
</tr>
<tr>
<td>Vancouver</td>
<td>WW</td>
<td>NW</td>
<td>NW</td>
<td>WW</td>
<td>WW</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>SW</td>
<td>W</td>
<td>SE</td>
<td>NW</td>
<td>E</td>
</tr>
</tbody>
</table>

Fastest Mile: Wind Speed & Direction (1 min. value observed)

Cold Months

June - Sept.

Warm Months
2.5.5 Katabatic Wind

Katabatic winds, the cold air flow from higher elevations to low areas, are experienced throughout Alaska being most pronounced in the colder regions in the interior, although even Juneau experiences a wide difference on temperatures between upland (sloping areas) and the low flat terrain which receives the cold air drainage from higher elevations. Normally a light to moderate wind or cloud cover will stir up the stratified air relieving the low lying areas from the extreme cold temperatures. This factor is important when selecting building sites within a particular area.17

2.5.6 Building Implications

In building design considerations for winter wind, the design priority for the direction of the mean wind or that of the strong, gusty wind which occurs two or three times a season would have to be resolved for each individual area. In addition, the built environment also has its influence on these wind patterns which can either increase or decrease the problems encountered. This micro climate which is created has the possibility of enhancing or degenerating the habitability of the area.

In regions with persistent winds such as in the arctic, the major building implications are:

1. the potential for snow drifting about the buildings, and

2. the cold air and air born snow infiltration into the building interior.

In the continental and transitional regions, the winter wind can have a beneficial effect by stirring up the extreme cold air which settles in low lying areas thereby raising the air temperatures in these areas. Then the major building implication becomes the infiltration through cracks and openings as well as the cooling effect on exterior building surfaces
(especially glass).

High winds pose structural problems as well as the increased heat loss problem. Regions adjacent to bodies of water such as the Arctic Ocean, Bearing Sea, Cook Inlet, and the Gulf of Alaska experience the higher winds which would have a greater impact on building forms such as high rise housing than on low rise, compact housing which could be protected from the cold winds.
2.6 SPECIAL CLIMATIC CONDITIONS

2.6.1 Objective

This section points out the combination of climatic conditions in the north which cause special building problems for differing areas within the north. The intent of this section is to define these conditions, indicate where they are most critical, and state the building implications due to their presence.

2.6.2 Humidity/Moisture Potential

The mechanics of humidity concerning moisture potential and temperature are explained in Appendix A under "Relative Humidity Chart and Moisture Potential Graph".18

The moisture potential of any particular area is dependent upon the temperature, since the continental zone experiences the coldest temperatures it also would have less moisture potential in the air. During the winter months Barrow and Fairbanks would have the least potential for moisture in the air. Talkeetna, Anchorage, and Minneapolis would be similar, while Juneau and Vancouver would have the greatest moisture potential.

Many problems occur in the cold dry areas where the moisture created by people, cooking, and washing within buildings migrates towards the exterior which is cold and cannot retain the high moisture content in the air. This moisture is often frozen in or on building materials.

High humidity becomes a comfort problem during summer when the temperature is high enough, see comfort zone on the bioclimatic chart, Appendix A. Most areas in Alaska have temperate summer temperatures. The interior region gets temperatures in the 80's and occasionally in the 90's, yet the relative humidity during the warm months ranges from 40% (2pm in the afternoon in June) to 78% (2am in the morning in July). The lowest value occurring during the warmest part of the day makes the area comfortable even during the warmer periods. During these same periods in Minnesota...
eapolis the daily maximum temperature average is in the 80's with maximums around 100°F while the relative humidity ranges from 53% to 82%. From the bioclimatic chart, 80°F and 60% humidity is beyond the comfort zone for most people.19

The design for summer heat and humidity, ventilation from the wind and more openings in buildings, has a much higher priority in more southern latitudes such as Minneapolis than it has in all regions of Alaska.

2.6.3 Blowing Snow

Combining wind, precipitation (dry snow), and temperature (cold) produces conditions ideal for blowing snow which has a tendency to accumulate behind any solid barrier on the downwind side blocking building exits, covering windows, etc. The areas in Alaska where this is a major building design problem is along the arctic slope and west central Alaska, areas which border the Arctic Ocean, Beaufort Sea, Chukchi Sea, and Bearing Sea, see figure 2.18. Coastal areas further south experience milder temperatures during winter normally making the snow too heavy to be transported by the wind.20
2.6.4 Permafrost

Permafrost is permanently frozen soil, material which normally stays at or colder than 32°F (0°C) over the years. Continuous permafrost refers to the northernmost areas in which all the terrain is permanently frozen ground to varying depths below the active layer. Discontinuous permafrost refers to the areas generally further south which tend to have permafrost on the north slopes of hills and flat areas which have poor drainage. Normally the south facing hillsides and well drained flat areas are free of permafrost. Further south is the area of sporadic permafrost where the permafrost is only found in isolated spots where little solar heat is obtained, poor drainage exists, temperatures stay low throughout the year, or combinations of these conditions.

In Alaska, continuous permafrost exists from the Brooks Range north to the Arctic Ocean. Discontinuous permafrost is present throughout the interior while sporadic permafrost occurs in the transitional zone encompassing Anchorage and Talkeetna, see figure 2.19. Southeastern Alaska is virtually free of permafrost.

Building implications associated with permafrost deal with foundation stability since melting of the permafrost can cause differential settlement or even collapse of the structure. Ice lenses and ice wedges are present in permafrost, should these melt they leave a void in the soil which sinks in leaving anything resting on the surface in an unstable condition. The areas of discontinuous permafrost in the Alaskan interior are more critical to build on than the permafrost in the arctic region since the temperature of the permafrost in the interior may be close to melting. Any change on the surface such as clearing the brush may melt the permafrost. Building on this type of ground should be avoided whenever possible.
2.6.5 Active Layer/Frost Heave

The active layer of the ground is that depth which freezes and thaws annually as the seasons change. Areas of the greatest active layer depth are those with the greatest temperature differences from winter to summer causing freezing temperatures to go deeper in the winter and a greater depth of thaw in the summer. The interior or continental climatic zone in Alaska has the greatest variation of active layer, from 2 feet up to 20 feet. Should the soil on which a building is constructed have a low moisture content (backfilled with non-frost susceptible material) and good drainage, the freezing (expansion) and thawing of the active layer presents little problem.
Since nearly all of Alaska experiences freezing temperatures, an active layer of varying depths can be found throughout the state. More southern maritime areas such as Vancouver do not experience the freezing of the ground to any great extent while in the continental zone of Minneapolis an active layer may be similar to that found in the Anchorage region in Alaska.

Frost heave occurs within the active layer of the soil and is the resultant building implication associated with the active layer. By definition, frost heaving is the expansion of soil due to the growth within it of extensive ice whose volume is greater than the (thawed) voids-volume of the soil. In order for frost heave to occur, we need freezing temperatures (winter), water in the soil (silt), and the capillary action of the soil to bring the water towards the surface where it freezes and expands (wick action).

Hence, any area within Alaska can experience frost heave depending on the soil makeup and moisture content within the soil. In the coldest areas the heaving will occur once in the fall when the ground begins to freeze for the winter. In more temperate areas the freeze/thaw cycle may occur several times over a winter due to intermittent cold spells and warm periods (above freezing).

Southern maritime regions do not experience frost heave due to the lack of non-freezing temperatures, yet more southern continental regions encounter problems with frost heave due to long periods below 32°F (0°C) during the winter.

While frost heave is present in more southern latitudes than Alaska it becomes a more critical problem in many areas in the north due to the combination of poorly drained soil (partly caused by surrounding permafrost) and the presence of silty soils.
2.7 SUMMARY

Some climatic conditions are more critical in building design for certain regions within the State of Alaska than other areas. The most important climatic conditions for each region are:

A. The Arctic Region
   a. Blowing snow and snow drifting
   b. Constant wind blowing
   c. Continuous permafrost conditions
   d. Small active layer/frost heave potential
   e. Cold temperatures year round
   f. Low sun angles with no sunlight in winter and 24 hours in summer

   In this region the primary building implications are (1) the potential for snow drifting and (2) the need to retain the stability of the frozen ground (permafrost). The latter causes special problems with regard to foundations and utility systems (water and sewer). The possibility of creating a more desirable micro climate through windbreaks is restricted by the possibility of snow drifting.

B. The Sub-Arctic Region
   a. Cold temperatures for long periods
   b. Low sun angles with short winter days and long summer days
   c. Dryness during cold months
   d. Ice fog production
   e. Less wind than arctic or maritime regions
   f. High degree of moisture migration (warm to cold)
   g. Discontinuous permafrost more sensitive when disturbed
   h. Large active layer/frost heave potential

   The locating/siting of housing in the sub-arctic environment is very important since picking the right spot can alleviate many potential problems. Areas
with permafrost, potential frost heave, and low lying cold air drainage should be avoided whenever possible. If this can be done, then the primary building concerns deal with temperature and solar radiation.

There is a tremendous contrast between the very cold relatively dark winters, and the relatively warm, bright summers. This great difference between summer and winter is one of the most important characteristics of the sub-arctic. Planning a living environment which responds to both summer and winter conditions becomes a challenge in the sub-arctic since the seasonal variations are so extreme.

C. The Southern Continental Region

The more southern continental region, in contrast to the sub-arctic region has more winter sunlight, shorter winter season, and much warmer summer temperatures. This primarily lessens the impact on operating costs for heating and problems related to cold temperature penetration (thermal bridging with related icing).

D. The Northern Maritime Region

a. Greater rain, snow, and ice
b. Higher winds
c. Presence of ocean fog
d. More moderate temperatures over the year

This region, being more damp and windy, primarily needs protection against winter winds and large snow accumulations which may cause structural damage as well as maintenance problems. Icy conditions throughout the winter make vehicle transportation hazardous especially when circulation patterns are located on slopes.

E. The Southern Maritime Region

The more southern maritime region experiences relatively mild temperatures as well as more sunlight during the winter months. Summer temperatures are
more moderate than continental regions making solar heat desirable for a large portion of the year. The absence of permafrost and heaving soils simplifies foundations and the moderate temperatures have less of an impact on the building fabric.
2.8 REFERENCES

1 Sunpath diagram for 62° north latitude constructed by the author, see appendix A.

2 Atmospheric Air Mass Chart prepared by the author from ASHRAE, Handbook of Fundamentals, p. 469, air mass = cosecant of solar altitude x ratio of barometric pressure: 29.92 in.hg.

3 Solar altitudes calculated from the formula shown in Appendix A, Part C.


7 Ibid.

8 Ibid.

9 Ibid.

10 Ibid.

11 Ibid.


13 Canada, Department of Transport, Meteorological Branch, Temperature and Precipitation Tables for British Columbia, Toronto, 1967

14 U.S., (NOAA), Local Climatological Data

15 Johnson and Hartman, Environmental Atlas
16 Canada, Department of Transport, Meteorological Branch, Climatic Normals, Volume 5, Wind, Toronto, 1968

17 Eb Rice, "Arctic Engineering (C.E. 603), Univ. of Alaska, class notes, 1973

18 Givoni, Man, Climate and Architecture,


20 Rice, C.E. 603

21 Johnson and Hartman, Environmental Atlas

22 Rice, C.E. 603

23 Ibid.
CHAPTER 3

BUILDING DESIGN RESPONSES

3.1 INTRODUCTION

3.2 PLANNING LEVEL 1: SITE LAYOUT/CIRCULATION PATTERNS
   3.2.1 Objective
   3.2.2 Solar Radiation
   3.2.3 Temperature
   3.2.4 Precipitation
   3.2.5 Wind
   3.2.6 Special Climatic Conditions (Blowing Snow)
   3.2.7 Summary
   3.2.8 References

3.3 PLANNING LEVEL 2: BUILDING SIZE, SHAPE, AND ORIENTATION
   3.3.1 Objective
   3.3.2 Solar Radiation
   3.3.3 Temperature
   3.3.4 Precipitation
   3.3.5 Wind
   3.3.6 Special Climatic Conditions (Blowing Snow)
   3.3.7 Summary
   3.3.8 References

3.4 PLANNING LEVEL 3: ACTIVITY/SPACE ARRANGEMENT
   3.4.1 Objective
   3.4.2 Solar Radiation
   3.4.3 Temperature
   3.4.4 Precipitation
   3.4.5 Wind
   3.4.6 Special Climatic Conditions (Blowing Snow)
   3.4.7 Summary
   3.4.8 References

3.5 PLANNING LEVEL 4: DETAILING ON THE BUILDING FABRIC
   3.5.1 Objective
   3.5.2 Solar Radiation
   3.5.3 Temperature
   3.5.4 Precipitation
   3.5.5 Wind
   3.5.6 Special Climatic Conditions
      A. Humidity/Moisture Potential
      B. Blowing Snow
      C. Permafrost
      D. Frost Heave
   3.5.7 Summary
   3.5.8 References
3.1 INTRODUCTION

This chapter illustrates building responses to the climatic conditions stated in chapter 2.

The previous chapter compared several northern climatic regions. The building design responses in this chapter may be applicable to a wide range of northern climatic regions, but the primary focus will be on the sub-arctic region as shown on figure 2.20 at the end of chapter 2.

The format is broken down into the four planning levels with each level illustrating responses due to implications caused by solar radiation, temperature, precipitation, wind, and special climatic conditions. The four planning levels are ordered from #1 (highest) to #4 (lowest) since decisions made at the higher planning levels have an effect on the impact of the climate at the lower planning levels. Planning levels include: 1 Site Layout/Circulation Patterns, 2 Building Size, Shape, and Orientation, 3 Activity/Space Arrangement, and 4 Detailing of the Building Fabric, refer to figure 1.9 in chapter 1.

Each planning level is summarized indicating the relative importance of the various responses to the climate. The priorities of many of the differing design responses will depend on the user's needs and preferences plus the particular site conditions. Because of this, the responses have been illustrated separately for each climatic factor (solar radiation, temperature, etc.) so that users/builders can design/evaluate housing as it responds to each individual climatic factor. The next chapter provides an example of evaluation for a particular site, combining the site factors with the climatic factors to establish a possible set of building response priorities for the more specific condition.
3.2 PLANNING LEVEL 1: SITE LAYOUT/CIRCULATION PATTERNS

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOLAR RADIATION</td>
<td>TOPOGRAPHY</td>
</tr>
<tr>
<td></td>
<td>TEMPERATURE</td>
<td>SEDIMENT</td>
</tr>
<tr>
<td></td>
<td>PRECIPITATION</td>
<td>SOILS</td>
</tr>
<tr>
<td></td>
<td>WIND</td>
<td>SODORUS</td>
</tr>
<tr>
<td></td>
<td>SPECIAL CONDITIONS</td>
<td>ADJACENCY</td>
</tr>
<tr>
<td>PLANNING LEVEL 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.1 Objective

This section is intended to point out design responses at this first level of planning which help to lessen the adverse effects of the climate at the lower levels of planning.

The establishment of a city infrastructure puts various restrictions on the built environment. The housing must follow vehicular and utility circulation patterns and be regulated by property lines adjacent to these circulation patterns. If the city infrastructure were planned to minimize the adverse effects of the winter climatic conditions and maximize the desirable climatic effects, the micro climate created at this first planning level could greatly enhance the habitability of the area and lessen the climatic implications on the built environment.
3.2.2 Solar Radiation

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning Level 1</td>
<td>Solar Radiation</td>
<td>Topography</td>
</tr>
<tr>
<td>Planning Level 2</td>
<td>Temperature</td>
<td>Geology</td>
</tr>
<tr>
<td>Planning Level 3</td>
<td>Precipitation</td>
<td>Soils</td>
</tr>
<tr>
<td>Planning Level 4</td>
<td>Wind Special Conditions</td>
<td>Hydrology</td>
</tr>
</tbody>
</table>

One of the most important aspects of design in the subarctic region is the use of solar radiation and natural light in the siting, layout, size, shape, and orientation of buildings with respect to one another since they directly affect the time and duration that sunlight will be distributed to each building (especially during the winter months).

Does a person have a right to sunlight? Does his home have a right to sunlight, especially if it is designed to maximize solar radiation in order to make it habitable and conserve non-renewable resources?

In North America, zoning ordinances are normally the only regulation which indirectly have an effect on the light and sunlight patterns. Single family housing within a city would normally have zoning controls which restrict the lot sizes, setbacks, building use, and building heights which effect the sunlight characteristics of the surrounding environment. Most zoning ordinances do not use a quantitative or qualitative measure of sunlight and/or skylight available to the exterior use spaces or the buildings themselves. So, from the southern latitudes of Florida to the northern latitudes of Alaska, the size and spacing of housing is very similar since zoning criteria changes little with latitude, see city maps in chapter 1, figures 1.5 and 1.6 for street/city layout. But, the amount of sunlight and desirability for sunlight changes radically with latitude and climatic conditions, and yet the built environment (micro-climate created) does not reflect this.
For centuries laws have been passed to protect the right to sunlight. Historically there have been periods of great concern for the protection of light and sunlight within the living and working environment. These concerns were originally based on health reasons since it was proved that the lack of sunlight was detrimental to one's well being. The present day concern for sunlight takes on a new dimension since it is based on the functioning of the building to make it habitable.

"Light and sunlight, according to the consensus of qualified opinion, constitute the most important factor in determining the desirable maximum height and bulk of buildings. Many attempts have been made to reduce the minimum desirable standards of light and sunlight to a qualitative basis. The British Law of Ancient Lights is the earliest attempt to assure a minimum standard of light to the ground story windows of all buildings. ... the Law of Ancient Lights dates back to the reign of Richard Coeur de Lion in the year 1189." ¹

In the U.S., many studies were done which attempted to establish a minimum standard of sunlight along with a means for evaluation. Unfortunately much of the effort done in this research was not put into practice.

"It is a matter of record that in developing a zoning ordinance for New York we spent a great deal of time trying to see if there might not be some way of interpreting these quantitative standards in the terms of a zoning ordinance that might be readily applied by the average architect, builder, or realtor. The upshot was that we found there were so many other complicating features that it would be impracticable to try to use a definite quantitative minimum standard of light and sunlight in the zoning ordinance;" ²

Most quantitative standards at the time tried to establish at least ½ hour of sunlight (equivalent of noon sunlight intensity) to a home unit window on the shortest day of the year.
It was claimed back in 1930 that New York, through its zoning, had accomplished the same sunlight and skylight standards as London even though it allowed greater building heights. This was justified because the sun angle in New York (251°) on the shortest day of the year is 11° higher than it is in London (15°) therefore allowing greater building heights while achieving equal sunlight standards. So, what are the consequences if this were applied to the far northern latitudes where the winter sun angle is only 5° instead of 251°? Figure 3.1 gives some idea with regard to the building spacing required for different latitudes to receive similar amounts of winter sunlight.

The ratio of vertical height to horizontal spacing required to allow winter sunlight penetration varies from 1:1.67 for 45°N.Lat. (higher latitude than New York City) to 1:8.5 at 62°N.Lat. Instead of 15' high buildings being spaced 25' apart, the buildings need to be spaced 127' apart to receive similar sunlight exposure on the shortest day of the year. This is not feasible since the buildings would have to be so spread out that they would use up too much land while providing housing for only a few people.

Since in the north it would be even more difficult to arrive at a quantitative standard to assure sunlight to all housing units, it makes more sense to evaluate building size, shape, orientation, and spacing on their shadowing (sun blocking) potential of exterior space and other buildings. The building response criteria put forward in this section is meant to be a tool for evaluating solar shadowing potential instead of trying to prescribe quantitative standards for sunlight or daylight.
DISTANCE \( (h) \) derived from

\[ h = \frac{a}{\tan A} \]

\[ a = 15' - 5' = 10' \]

\[ A = 1.0^\circ, 4.5^\circ, 6.5^\circ, 10.5^\circ, 21.5^\circ \]

\[ h = 358', 127', 88', 34', 25' \]

**Figure 3.1**

Building spacing required at various latitudes on Dec. 21st to allow sunlight penetration 5' above grade for 1 story (15').
The orientation of the circulation system has a major effect on the arrangement of buildings and the use of exterior spaces. North/south street orientation is best for allowing sunlight onto exterior spaces and for establishing "corridors for sunlight" during the winter. Compact housing forms orientated parallel to the north/south street would cast a minimal shadow during midday, but the units would get only a small portion of sunlight on the east and/or west walls and windows. The most unfortunate problem with north/south street orientations is that they usually have east/west street connectors, the famous grid pattern. Having closely spaced buildings along the east/west streets is the least desirable solution with regard to solar shadowing since they put the north side exterior spaces in shadow for over $\frac{1}{2}$ of the year. With this in mind, street patterns should maximize north/south street orientations and minimize east/west street orientations utilizing diagonals (nw/se, ne/sw) for connectors. The southeast/northwest streets will get morning sun along with adjacent exterior yards, and in the afternoon the southwest/northeast street receives sunlight.
When buildings are placed along the circulation patterns, the property lines should be flexible enough to allow differing building orientations. Having this flexibility the designer/builder can manipulate the structure more easily to respond to the climatic conditions at planning level 2.

The greatest potential for sunlight from the south occurs along diagonal street patterns since the distance which the buildings are spaced apart is the greater diagonal distance.

The individual buildings of any micro environment should be arranged so that the smaller buildings are to the south of larger more massive buildings in order to minimize the shadowing effect of the larger buildings during winter.
The local topography also has an effect on shadowing potential. Building on south facing hills helps to reduce the length of shadows during winter providing the opportunity for closer building spacing while still receiving winter sunlight. Similar to conditions on level ground, the taller more massive buildings should be located near the top of the slope (to the north) with the smaller buildings to the south, southeast, and/or southwest.

For an example of the topographic effect on building spacing with regard to sunlight penetration, the spacing for 3 story (35') buildings range from 80' at 45° latitude to 375' at 62° latitude for similar winter sunlight penetration on flat topography. The 375' spacing can be reduced to 118' (less than 1/3rd the distance) when on a 10° slope and have equal sunlight penetration, see figures B.1, B.2, B.3, B.4 in Appendix B.
3.2.3 Temperature

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning Level 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning Level 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning Level 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning Level 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A. Topographic Locational Considerations:

Hillsides and higher elevations should be used for development due to the cold air flow (katabatic wind) in the winter which settles in the lowest areas. This cold air flow can make the valley floor as much as 30° to 40°F colder than the hillsides several hundred feet higher.

Much like the cold air flow, ice fog collects in the low lying areas during periods of extreme low temperatures (below -25°F) which are characterized by little air movement and clear skies. In most cases the fog is created by man (cars, homes, power plants, industry - anything which puts moisture into the air).

With increased development, it is difficult to avoid the production of ice fog during extreme cold conditions, but knowing that the fog settles in the
lower elevations along with the cold air, development can avoid areas of high ice fog potential. This is especially important when planning for development which needs good winter visibility such as an airport.

B. Physical/Socio-Cultural Locational Considerations - Compact Planning versus Dispersed Planning:

In the arctic region the close grouping of buildings and the containment of many facilities in one structure is more critical than in the subarctic region due to the presence of year round cold temperatures, continuous permafrost, constant wind, blowing snow, and lack of vegetation.

"The climate, terrain and permafrost conditions severely inhibit the options for servicing buildings in the north. Self-contained systems for heating and recycling water are technologically feasible, but prohibitively expensive on an individual housing unit basis. Even if such systems become economically feasible, there is reason to concentrate housing units in tight groupings because of the ecological disturbance, the expense of roads and paths, and the atmospheric effects of keeping an automobile engine running while it is parked." 

In the subarctic region there is a need for a compact community during winter and a dispersed community during summer in order to optimize for the differing seasons. During the winter transportation, utilities, and maintenance can be major problems/expenses in a dispersed community.

On the national scale, transportation accounted for 25% of the total end product energy consumption in the U.S. in 1970. Only 25% of this energy was
converted to "work" while 75% was "waste" (lost in heat and exhaust). 7

Carefull consideration must be made in the northern environment when establishing transportation means and patterns. First, is the automobile the appropriate means of transportation? Besides the numerous hassles involved with the comfort, cost, and maintenance of an auto in the winter, the auto gets much less milage per gallon of gas in cold temperatures (quite often about \( \frac{1}{2} \) normal). So the already bad efficiency drops even lower. When combining this with the fact that the autos, trucks, and buses account for nearly 20% of the total U.S. fuel consumed, while producing only 25% efficiency, it would seem important to plan a reliable transit system and /or a compact siting of services, schools, offices, and living environments which would minimize the need for the private auto within the city environment.

Since in dispersed developments the automobile will not be eliminated and areas will be developed which are remote enough to require an auto (quite often a 4 wheel drive) some adverse conditions must be considered:

1. Steep inclines, approximately 10% or greater with icy conditions limit:
   - Accessibility of private autos
   - School bus pick up and drop off
   - Postal and garbage service
   - Emergency access

2. Parking lots in downtown areas where people shop for an hour or two tend to have high carbon monoxide readings due to the inversion layers of air (prevelent in winter) combined with the idling of cars which people do for hours in order to always have a warm car. These areas also accumulate large amounts of ice fog during extreme cold periods. Plug-ins are costly to install as well as for the consumer to use.
3. Snow removal from October to April with a winter's accumulation varying from 30" (2 1/2 feet) to over 170" (14 feet)

4. The availability of electrical plug-ins or heated parking garages becomes more important the colder it becomes. When temperatures drop below \(-20^\circ F\) for any length of time many cars will not start or operate well if the engine and battery have had time to cool off. In Fairbanks, electrical plug-ins are available (normally at a cost) so that the circulating heaters/oil pan heaters can keep the engine warm and the electric battery blanket can keep the battery from cooling off and loosing power.

The issues of transportation and location (distance) from places of work, school, etc. are complex. It's been my experience that those who can afford to use a private auto will use it just as in any other area in the U.S. especially if conditions make it necessary. Should a transit system be developed, its dependability is critical because people are not willing to spend any length of time waiting in \(-30^\circ F\) temperatures in the winter darkness. Also, once people are able to establish their suburban sprawl with homes, shopping areas, schools, offices, and industry spread out in many areas it becomes more difficult to establish a transit system which can satisfy most of the people.

Reduced capital costs and reduced maintenance costs add to the desirability of compact planning. Reduced capital costs result from shorter access routes. Capital costs include such items as paved roads, curbs, sidewalks, sewers, storm sewers, water mains, street lighting, fire hydrants, and power distribution. Reduced maintenance costs result from servicing a shorter linear footage of access routes. Maintenance costs include such items as road maintenance, snow clearance and policing.
Problems With Compact City Planning

Compact communities also can produce problems associated with living in the north. In evaluating the performance of the town of Svappavaara, Sweden, the designer, Ralph Erskine, states that one overriding difficulty that the community faced was that the people did not have a tradition of living in a "tight" community. The developers of the community gave the people moving into this unique environment very little instruction on how to use the community. Some of the disadvantages of the compact plan included noise disturbances, people active all night during the long summer; a lack of variety, there were alternative types of dwellings but only one "situation"; and family groupings proved too large in practice (70 families per grouping).

According to the designer: in retrospect, perhaps the whole idea of a surrounding wall to reflect light into the community and provide snow and wind protection, is not appropriate. Perhaps a more fragmented plan providing more variety and visual complexity, is a better solution.

Original plan of Svappavaara, Sweden designed by Ralph Erskine

Figure 3.8
Another study (military housing at Ft. Wainwright, Alaska) indicated that respondents in courts (fig. 3.9) were more dissatisfied with their compact conditions than respondents living in the row houses (fig. 3.10). They felt crowded indoors and out, complaining that the yards were inadequate. The exceptions to this were the respondents living in end apartments since they had three yards instead of two. Children tended to play in the parking lot area which adjoined the backyard area within the enclosed court area amplifying noise disturbances and the compacted feeling.
Conclusions

With proper site layout the compact city plan can create a desirable place to live and work. Some guidelines in this respect are:

A. Minimize the everyday use of automobile transportation to the downtown by keeping the distances from housing to work, services and schools within easy walking distance or on the route of a public transport system.

B. Create a desirable micro-climate through the control of winter winds and the maximum penetration of winter sunlight (orientation of the circulation patterns and the arrangement of the building sizes).

C. Control development beyond the "townsite" in order to retain natural forest and recreational potential within close proximity.

D. Avoid enclosing housing in too tight a design pattern; for example the courts at Ft. Wainwright or the wind protected "closed" environment in Swedish compact towns.
3.2.4 Precipitation

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOLAR RADIATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEMPERATURE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PRECIPITATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WIND</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SPECIAL CONDITIONS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOPOGRAPHY</td>
<td>Topography</td>
</tr>
<tr>
<td></td>
<td>SOILS</td>
<td>Soil</td>
</tr>
<tr>
<td></td>
<td>VEGETATION</td>
<td>Vegetation</td>
</tr>
</tbody>
</table>

During winter months, the landscape is covered with snow which is vital for insulating underground utilities against the extreme cold. Snow accumulation causes conflicts between autos and pedestrians.

During the winter months, the snow accumulation obscures the normal automobile buffers such as curbs, car stops, and other separators designed to keep the auto separated from buildings, pedestrians, and vegetation.

This condition coupled with the fact that people want to park as close to their destination as possible during the cold winter causes conflicts between autos and pedestrians as well as buildings. Barriers high enough to stop cars in winter should be considered for most buildings and pedestrian routes where the building exterior, pedestrians, and vegetation need to be protected.
The light, dry snow in the north has insulating qualities similar to that of fiberglass insulation. This insulating quality is often effective in reducing the depth of freezing in the ground, hence keeping utilities from freezing. In areas where the snow is cleared away during winter (streets, etc.), the depth of freezing goes deeper. In addition to this, tall buildings which cast a long shadow may block the summer sun which normally helps to thaw the ground. These factors could lead to the freezing of vital utility lines or increase the depth which they have to be buried.

![Diagram](image)

**Figure 3.13**

![Diagram](image)

**Figure 3.14**
3.2.5 Wind

Depending on the location within the North, the wind can become one of the major physical factors in design (arctic and maritime regions). In most areas of the subarctic region the need for breaking the wind is not as critical.

On the macro scale, land forms (topography) and vegetation (stands of evergreen trees) can function as windbreaks. By building on the leeward side of a hill, avoiding the brow of a hill or ridge where higher winds occur and the valley floor where cold air movement occurs, wind velocity can be minimized. Stands of evergreen trees (approx. 40 feet high) can reduce the wind velocity up to 50% 200 feet downwind from the trees. Reduction in wind velocity reduces building heat loss and wind chill factors.

The size, shape, and placement of buildings have an effect on localized wind conditions and blowing snow patterns. Acting as solid windbreaks, buildings (approx. 40 feet high) can reduce the wind velocity 100% just lee of the building and 50% at distances 400 to 600 feet downwind. Where buildings blocking winter winds have spaces between them, the wind may get funneled through those spaces increasing the wind speed. Where blowing snow is a possibility, snow drifting can occur on the lee side of windbreaks such as hedges, trees, fences, and buildings.
The town of Fermont in northern Quebec is a compact town design with a linear wind screen building along the north side of the site. Housing is on the south side with south-southwest/north-northeast and southeast/northwest street patterns. While the street orientations were primarily situated to reduce snow drifting potential from prevailing wind directions, the layout affords morning and afternoon sunlight corridors. The taller structures are to the north (wind screen building) so as not to block sunlight in habitable areas.

The site slopes to the southeast and southwest helping to expose more area to the winter sunlight from the south.
The concept of the wind screen building appears in several town designs by Ralph Erskine, Svappavaara in northern Sweden (figure 3.6) and Resolute Bay, N.W.T., Canada (figure 3.16). Resolute Bay is in the well frozen, treeless Arctic at 74°N. latitude. The windscreen perimeter structure, open to the south, includes the town center, shops, hotel, offices, apartments and row housing. The individual buildings within the wind protected micro climate are designed to minimize wind resistance, turbulence and undesirable snow drifting. Projections and irregularities are minimized. Additions and alterations by the user to the aerodynamic forms will be discouraged, but the open plans are designed to allow flexibility inside the structures.
3.2.6 Special Climatic Conditions

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLANNING LEVEL 1</td>
<td>CLIMATIC FACTORS</td>
<td>SITE FACTORS</td>
</tr>
<tr>
<td>PLANNING LEVEL 2</td>
<td>CLIMATIC FACTORS</td>
<td>SITE FACTORS</td>
</tr>
<tr>
<td>PLANNING LEVEL 3</td>
<td>CLIMATIC FACTORS</td>
<td>SITE FACTORS</td>
</tr>
<tr>
<td>PLANNING LEVEL 4</td>
<td>CLIMATIC FACTORS</td>
<td>SITE FACTORS</td>
</tr>
</tbody>
</table>

Blowing Snow/Snow Drifting

The amount of snow carried and deposited by the wind depends on:

1. the amount of snowfall and type of snow (wet or dry),
2. the wind velocity, and
3. the sweep of snow cover upwind

Blowing snow occurs at wind velocities in excess of about 8 mph. The sweep of snow cover upwind could come from large cleared areas, large parking lots, or even many flat rooftops. The downwind side of large open areas should be assessed as to the effects of snowdrifting.

At the site planning level it's important to protect major access routes from being blocked by snowdrifts. Building exits and circulation routes (roads, pedestrian ways) should have priority.

![Diagram of snowdrifts and wind direction](image-url)
To remedy the problem of snow drifting in unwanted places three approaches have been used:

1. keep upwind sweep areas to a minimum using vegetation wherever possible,
2. create barriers upwind of places to be protected such as the snow fences near highways,
3. let the blowing snow pass on through such as is done in the Arctic where the buildings are elevated to enable the wind to blow the snow on past the buildings. This does not, however, protect the building from the cold wind.

**FIGURE 3.18**
3.2.7 Summary

Listing of planning objectives to be considered at planning level 1 are:

A. Solar Radiation
   a. Orientate circulation system to maximize winter sunlight
   b. Layout/space buildings for maximum sunlight distribution
   c. Use of topography to maximize winter sunlight distribution

B. Temperature
   a. Avoid building in low lying cold air pockets
   b. Avoid development in high ice fog potential areas
   c. Advantages of compact city planning
      Transportation: pedestrian routes and public transport more feasible
      Utilities: shorter runs, less capital costs
      Less operation and maintenance costs
      Greater potential modification of microclimate
   d. Disadvantages of compact city planning
      Socio-cultural makeup: people not used to living in a compact environment
      Noise disturbances and the feeling of being crowded
      Seasonal activity changes intensify the confined feeling

C. Precipitation
   a. Avoid conflicts between autos and pedestrians/buildings during the winter season when ground is covered with snow
   b. Use winter snow cover as an insulator against cold temperatures

D. Wind
   a. Slow or block undesirable winter winds
   b. Avoid funneling cold wind into habitable areas
E. Special Climatic Conditions: Blowing Snow

a. Minimize the blocking of roads and the blocking of entrances, exits, and windows by snow drifting

b. Control the location of snow drifting

When considering all the climatic factors together some have a greater impact than others, especially from one climatic region to another. The following are the most important in creating a desirable living environment:

A. Avoid building in low lying areas which have poor drainage (high frost heave potential), accumulate cold air during winter, and have greater potential for retaining ice fog.

B. Layout buildings and circulation patterns to maximize sunlight, minimize snow drifting, control winter winds, and avoid wind funneling. Conflicts can occur especially in areas where the snow drifting potential is high. In most areas within the subarctic the maximizing for sunlight would take preference over control of wind and snow drifting since winds are normally light and snow drifting minimal. In the arctic region design for snow drifting and wind would take preference over sunlight design.

C. Use the existing topography to maximize sunlight and minimize winter wind. A similar conflict occurs with the use of topography. In the sub-arctic region a south facing hillside is normally much preferred over a north facing slope even if winter winds are from the south. Permafrost on north facing hillsides is also a potential problem in the subarctic. East or west facing slopes may be preferred where views and/or wind protection predominate since solar radiation is still attainable during winter.
3.2.8 References

1 George Ford, Building Height Bulk and Form, Harvard City Planning Studies 11, 1931, p. 62.
2 Ibid., p. 67.
3 Ibid., p. 63.
13 van Ginkel, "New Towns in the North".
15 P.A. Schaerer, Control of Snow Drifting about Buildings, CBD 146, 1972, NRC, Ottawa.
3.3 PLANNING LEVEL 2: BUILDING SIZE, SHAPE, and ORIENTATION

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLANNING LEVEL 1</td>
<td>Solar Radiation</td>
<td>Topography</td>
</tr>
<tr>
<td>PLANNING LEVEL 2</td>
<td>Temperature</td>
<td>Geology</td>
</tr>
<tr>
<td>PLANNING LEVEL 3</td>
<td>Precipitation</td>
<td>Soils</td>
</tr>
<tr>
<td>PLANNING LEVEL 4</td>
<td>Wind</td>
<td>Vegetation</td>
</tr>
</tbody>
</table>

3.3.1 Objective

This section is intended to point out building design responses at the second level of planning (the individual building size, shape, and orientation) which help to lessen the adverse climatic implications and maximize the desirable climatic implications.

Planning for solar radiation, temperature, precipitation, wind, and special climatic conditions at this planning level can lessen the impact of adverse climatic conditions on activity spaces as well as the building fabric, planning levels 3 and 4.
3.3.2 Solar Radiation

Solar radiation can have a major influence on the building size, shape, and orientation. Building design responses mentioned in this section which influence these factors are:

1. Optimum shapes to minimize solar shadowing,
2. Possible solutions for sunlight access to the interior of larger buildings (size),
3. Building shapes which optimize the solar heat input and conductive heat loss, and
4. Optimum orientations for winter sunlight (visual) and orientation for maximum heat gain.

Solar shadowing of buildings on one another as well as on exterior space is a major design influence on the buildings size, shape, and orientation. In the subarctic north where winter sunlight is at a premium, it's important to minimize the solar shadowing of buildings.

Some of the basic shapes which expose minimum exterior surface area also cast a minimal shadow such as the dome, pyramid, or cube form. The following diagrams compare these shapes, which all have a similar volume, with less energy efficient shapes, the tall, thin building and the long, narrow building.
BUILDING SIZE & SHAPE EFFECT ON SHADOWING #1 SOUTH SUN

SHADOW LINE @ 10° APPROX. EQUAL INTERIOR VOLUMES

ELEVATION

PLAN
1. LINEAR BLOCK
2. TALL BLOCK
3. CUBE BLOCK
4. PYRAMID
5. DOME (HEMISPHERE)

SHADOWS OF BLOCKS WHICH CONSOLIDATE VOLUME IN CUBE, HEMISPHERE, AND PYRAMID

FIGURE 3.19
Figure 3.20

- Building size and shape affect on shadowing.
- Shadow lines at 10°.
- Approx. equal interior volumes.
- Linear building shadow (45° to sun).

Figure 3.21

- Building size and shape affect on shadowing.
- Shadow lines at 10°.
- Approx. equal interior volumes.
- Linear building shadow (parallel to sun).
- Tall building shadow. (Largest)
Tall, thin and long, narrow (east/west running) buildings cast longer and wider shadows denying sunlight to a greater area. Closely spaced building units running east/west will have a similar shadow effect as the long, narrow building, putting streets, yards, and the south faces of other buildings in shadow for much of the winter. The tall building casts long shadows in all orientations as well as at any time of the day when the sun angle is low. The linear building casts the largest shadow when perpendicular to the sun and a much smaller shadow when parallel to the sun. Since the sun sweeps from east to west, a long narrow building, no matter the orientation, will cast the largest shadow, as shown in figure 3.19, sometime during the day.

The cube, hemisphere, and pyramid cast minimal shadows in all directions (different solar azimuths). As can be seen with the pyramid, the smaller the building near the top, the smaller the shadow is farthest from the building.

No matter what the building shape, the larger the building mass, the larger solar shadow it will have; so, large buildings can block sunlight from a substantial area to the north of the building for a large portion of the year. When larger buildings are built, the adjacent areas to the north of them should not be exterior activity spaces since it's use would be limited to a short summer period when the sunlight could penetrate the space.

The sloping of the structure's roof can also help to decrease the shadowing effect. During winter, the shadow can be greatly decreased when the edge farthest from the sun is lower than the near edge. The roof angle should be at least 10° (approx. 2 in 12). When the ridge is centrally located as in a pyramidal shape the shadow is minimized in all directions, see figure 3.22.
Building Size and Solar Radiation

The larger the building, especially a compact building form, the greater the problem of achieving sunlight penetration to a large area of the building interior. When large structures are used for housing, providing sunlight to the maximum number of residents can be difficult.

When placing home units within an enclosed compact building shape instead of single or attached units (row housing), there is normally only one exterior exposure for each unit, the other exposure faces an interior space. Units facing in a northerly direction are denied sunlight for much of the year. Both these problems could be solved by opening up the structure's interior to winter sunlight which means having a glazed portion facing south. This approach has been used in a large housing structure in northern Russia (± 69°N. Lat.).
"This concept has also been developed for Norilsk in the form of a 26 story pyramidal building to house 2,000 persons. In this case, the court is open to the south side of the pyramid which is glazed, and the housing units are on the three remaining sides."  

See figure 3.23 for a diagrammatic sketch of this approach.

**FIGURE 3.23**

- Building Shape and Solar Radiation

  When optimizing building shapes for solar heat input and conductive heat losses and ventilation, the seasonal changes must be taken into account. During the coldest months, it is more economical (fuel consumption) to minimize the exterior surface area, as well as high heat loss window area, than it is to maximize the south exposure to capture winter (Nov. to Feb.) solar heat gain, see figure 3.24.
During spring, summer, and fall, it becomes advantageous to utilize the heat from the solar radiation to help heat the home interior. If the building exterior shell is heavily insulated in order to keep heat inside, it does not make a good passive solar heat collector; the well insulated walls will help prevent the solar heat from entering the home. To use the solar heat it becomes necessary to:

1. open up the interior to direct solar radiation for immediate warmth,
2. expose elements of high thermal mass for passive solar heat storage, and/or
3. open the home interior to solar heated "greenhouse spaces".
The optimization of solar radiation on the exterior shape depends on the slope and location of window areas allowing solar penetration, and the slope and location of thermal masses allowing thermal heat storage. Since the sun's angle of incidence on a glass window may vary as much as \(45^\circ\) from the \(90^\circ\) perpendicular without appreciable loss of transmittance or increase of reflectance, the shape/slope of the windowed exterior can vary considerably without reducing the solar heat penetration to the building interior.

![Diagram showing sun angles and solar heat spread](image)

**Figure 3.25**

For thermal masses the sun angle is more critical since the same solar heat which is absorbed by the mass, becomes spread out over a greater area when the sun is not perpendicular to the surface.

![Diagram showing vertical and horizontal mass](image)

**Figure 3.26**
For interior thermal masses at 62° north latitude, the only time of the year that a floor can receive higher solar radiation values than a vertical wall is from early May through early August on a south facing orientation. At all other times of the year and orientations the vertical wall has a higher potential for solar heat collection (more normal to the sun's direct rays). A thermal mass wall with a 62° south facing slope as in figure 3.27 will receive +30% more yearly direct radiation than a vertical wall and +45% more than a horizontal surface.

The exterior shape can be designed to minimize exterior surface area with fenestration located to allow solar penetration to interior thermal mass with optimum shape for passive solar heat collection, see figure 3.27.
Using thermal mass to optimize solar heat on the exterior skin limits the building shape more than the use of interior thermal mass as well as having potentially higher heat loss due to less resistance to heat flow than a well insulated exterior skin. Figure 3.28 illustrates how solar radiation can be maximized on the exterior thermal mass at the equinox, spring and fall, with the building shape - 62° south facing slope to 90° (vertical) at east and west points. Snow cover over the roof area helps keep heat in while sun heats sloped east, south, to west walls throughout the day. Roof slope to the north helps minimize the effect of solar shadowing.
• Building Orientation and Solar Radiation

Orientating a building for maximum winter sunlight for the greatest number of inhabitants becomes more of a problem when the housing units are more compact such as townhousing and condominiums/apartments. Often living units end up with their only exterior orientation to the north, northeast, or northwest in which only mid-summer sunlight has a possibility of making it to the unit.

It's interesting that in Russia the building instructions will not permit a single living unit to be orientated to the north (315° to 30°, 360° = north) with that orientation as its only exposure. In larger living units (2 to 5 rooms) one or two rooms may be orientated in the restricted north direction, see figure 3.29.

As a sunlight exposure minimum recommendation, compact housing units should not have their only orientation towards the north. Any unit with an orientation to this direction should also have exposure in another, more sunlit, direction.
Figure 3.30 shows possible solutions for making sunlight available to housing units which normally would only have a northern exposure.

Units #1 and #4 have north exposure as well as east or west exposure. Units #2 and #3 which only have exposure to the north should:

1. have clerestory windows to the south allowing sunlight penetration,
2. extend through to the south side of the building, or
3. receive south sunlight from an interior open space to the south of the units.

These criteria should also be applied to northeast and northwest orientations.
The following analysis compares building orientations with regard to solar heat gain. Based on a comparative analysis between the long, narrow building (townhouse type structure) and the compact building (cube form) with various orientations using data for 61° north latitude (Whitehorse), the following ranking is presented based on direct solar radiation on vertical surfaces.7

**Long, Narrow Building**
- Wall ratio: 3:1
- Wall surface area: 8
- Area: 3

**Compact Building**
- Wall ratio: 1:1
- Wall surface area: 6.92
- Area: 3

**Building Type and Orientation Ranking** (most to least radiation)

A. Total year:

1.  
   ![Diagram](image1)

2.  
   ![Diagram](image2)

3.  
   ![Diagram](image3)

4.  
   ![Diagram](image4)

5.  
   ![Diagram](image5)

6.  
   ![Diagram](image6)

B. Winter (Nov. - Feb.)

1.  
   ![Diagram](image7)

2.  
   ![Diagram](image8)

3.  
   ![Diagram](image9)

4.  
   ![Diagram](image10)

5.  
   ![Diagram](image11)

6.  
   ![Diagram](image12)

C. March/September equinox: long building orientations have approximately equal radiation, compact buildings have + 14% less radiation than the long buildings.

D. Spring, Summer, and Fall (April - October)

1.  
   ![Diagram](image13)

2.  
   ![Diagram](image14)

3.  
   ![Diagram](image15)

4.  
   ![Diagram](image16)

5.  
   ![Diagram](image17)

6.  
   ![Diagram](image18)
With the long narrow building, orientation change effects the distribution as well as the amount of direct radiation on a seasonal basis. The east/west orientation receives +35% more radiation in winter and +19% less in summer than the north/south orientation. The amount of radiation on the southeast/northwest and southwest/northeast orientations are in between the values for the north/south and east/west orientations throughout the year, 10% to 17% more than in winter and 12% more than in summer. On a yearly basis, the long, narrow building receives +15% more radiation than the compact building, but also has 16% more surface area at the exterior walls increasing heat loss potential possibly overriding the increased solar heat gain input.

The orientation of the compact building has more of an effect on the solar heat distribution on the wall surfaces than it has on the total amount of direct solar radiation received by the building. The two orientations, have nearly equal solar radiation for the year with each month varying only 1% to 2% from each other. The orientation has the winter solar radiation distributed to two orientations instead of one south facing orientation. This can help distribute heat and light to more of the house or housing units. Since the greater distribution of the days light and heat is regulated primarily through the use of fenestration, the orientation may afford a better combined use for windows since glass areas can be combined which would let solar heat and light penetrate (SE/SW) as well as allow taking advantage of more view potential from east to west.

Since solar heat gain is minimal during the winter months, orientations which maximize solar heat gain for spring, summer, and fall should be considered best for optimizing solar radiation.
Building Size and Temperature

Optimizing the building size for the cold winter temperatures cannot easily be solved by a large megastructure and still take into account the needs and expectations of the inhabitants. According to a study at the Cold Regions Research Engineering Labratory in New Hampshire:

"A tall thin structure much above 6 stories is less economical than modules used alone. Strip structures and flat square structures are better than similar modules used singly but cubical structures are most economical. The optimum cubical condition appears to occur when 100 to 200 modules are grouped into a 5 to 6 story cube."

Dealing with the implications of the compacted living environment, Ralph Erskine states the importance of contact with the natural environment which large megastructures help to eliminate:

"The structure of the town itself can be of vital importance in improving the climate within its boundaries, and with modern techniques almost any degree of protection can be achieved. One of the most exciting ideas which comes to mind when first presented with these problems is that of the township which is a single enormous building complex, or a township covered by domes or suspended membranes. In the most extreme conditions of the Arctic or Antarctic, these could be the most suitable ways of providing climatic defense. The physical convenience of such a township would be very great, and it would tend to be economical to run and to heat. The greatest difficulties
would probably be of social and psychological nature since such a town could easily be institutional and introvert, and though openable parts of the structure could give certain contact with the outer world, this would tend to be indirect and tenuous. Negative experience has been reported from northern encampments where people have been able to live without contact with the outer world that surrounded them, and it has been suggested that less sophisticated organization has been more successful.  

Since the solar radiation produces minimal heat gain during mid-winter, the building/home size for this season is better determined by the temperature, wind, and precipitation conditions along with utility, transportation, and service costs and restrictions. This would lead to a compact design with larger structures housing greater numbers of people closer to necessary services and facilities—compact city design. Placing all housing, services, and businesses within a single megastructure or within "200 module 6 story cubes" may satisfy utility, energy efficiency, and convenience; and placing individual homes on ½ acre lots throughout the countryside may satisfy the need for contact with the natural surroundings, each solution satisfies some portion of the housing need. A variety of building and home sizes normally prevail in order to meet the needs of a variety of people as well as taking advantage of the seasonal variations available in the northern environment.

As an example, the new town of Fermont in northern Quebec (see figure 3.15) developed four general types of dwelling units for the townsite. About 1/3rd of the dwelling units are apartment dwellings; 1/3rd are townhouses or semi-detached dwellings; and 1/3rd are detached single-family dwellings.

"Admittedly, the single-story detached dwelling units, like other low-profile units, are not congruous to the sub-arctic climate. However, citizen participation in the design process necessitated their utilization although in a modified form. It was deemed important to respond to psychological needs of some future
residents who aspired to live in "bungalows" like "other people" farther south."

Similar circumstances have been encountered in Northern Europe:

"Concentration gives exceptional advantages in the north if once it is emotionally acceptable, but I have experienced the difficulty of this type of innovation when working in the town of Kiruna, in northern Sweden." 12

"It is curious, but perhaps inevitable, that farther south, where the need for these ideas is far less urgent, I have usually found them more readily acceptable. Possibly the new building types for northern Canada must first be built in Montreal or Vancouver?" 13

To establish an optimum building size in the subarctic north, input from the socio-cultural makeup of the inhabitants as well as the implications from the physical factors are needed.

- Building Shape and Temperature

Minimizing the surface area exposed to the cold (the same usable interior space) exterior air helps to keep heat loss in walls and roof to a minimum. Exterior surface areas which approximate a hemisphere have less surface area exposed to the cold temperatures than a linear or tall, thin building. Other forms such as cubes and pyramidal shapes also have limited amounts of exterior surface area. The height of the building should be close to the width and depth of the building, see figure 3.31.

![HEMISPHERE](image1)
![CUBE](image2)
![PYRAMID](image3)

**FIGURE 3.31**
When comparing the interior usable volume to the exterior surface area certain shapes contain space which has limited use due to the height and shape of the space (figure 3.32). Standard furniture, appliances, and shelving/cabinets do not fit readily into those spaces although they could be used for storage or pipe chases if not closed off from the warm interior air flow.15

Building shape and volume can also influence the movement of interior air. A dome shape with a central heat source and clear space for air movement along the exterior walls, mixes its own air; the warm air rising in the center, then falling back down towards the floor along the walls where the air is cooled, see figure 3.33.16
Another factor effecting building shape is the use of building relief and articulation. Building relief or unnecessary articulation of the basic building shape have negative effects on the building's thermal performance. Relief on a facade causes added thermal stress by shadowing parts of the facade as well as providing points for heat extraction from the building, see figure 3.34.

"Coming back to this matter of heat transfer, you all know what an air cooled motorcycle engine looks like. To dissipate heat generated more quickly the surface of the engine is enlarged in the form of fins. It would be foolish to apply this same principle to buildings in an extremely cold climate. In winter you notice that every exterior corner in a building is a point of frost concentration."
3.3.4 Precipitation

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TEMPERATURE</td>
<td>SPECIAL CONDITIONS</td>
</tr>
<tr>
<td></td>
<td>PRECIPITATION</td>
<td>POTOGRAPH</td>
</tr>
<tr>
<td></td>
<td>WIND</td>
<td>SOILS</td>
</tr>
<tr>
<td>PLANNING LEVEL 1</td>
<td></td>
<td>GEOLOGIC</td>
</tr>
<tr>
<td>PLANNING LEVEL 2</td>
<td></td>
<td>VEGETATION</td>
</tr>
<tr>
<td>PLANNING LEVEL 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Building Shape and Precipitation

Any area with substantial snowfall will experience the problem of snow and ice breaking or sliding off buildings. Steeper sloping roofs have the higher slide potential especially when made of sheetmetal or aluminum. Shingle type roofs will reduce the chance of snow slides due to the many irregularities the snow adheres to. South side exposures quite often have their snow melt away before it has a chance to slide off in mass. On the north side, not getting the solar radiation to melt the snow, the snow may slide off in mass during the spring when temperatures are high enough to loosen the snow from the roof (figure 3.35).

Taller buildings adjacent to sidewalks, streets, etc. need to be particularly careful not to have potential snow slides onto these circulation routes, see figure 3.36.
3.3.5 Wind

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOLAR RADIATION</td>
<td>TOPOGRAPHY</td>
</tr>
<tr>
<td></td>
<td>TEMPERATURE</td>
<td>GEOLGICAL</td>
</tr>
<tr>
<td></td>
<td>PRECIPITATION</td>
<td>SOILS</td>
</tr>
<tr>
<td></td>
<td>WIND</td>
<td>MICROCLIMATE</td>
</tr>
<tr>
<td></td>
<td>SPECIAL CONDITIONS</td>
<td>AGROCLIMATIC</td>
</tr>
</tbody>
</table>

- Building Size and Wind

In areas surrounded by vegetation, protected by the topography, or protected by other structures, taller buildings can extend into regions of high wind velocities. This increased wind velocity can mean greater strength required in the structural design, exterior cladding material must be resistant to the higher velocity, and higher heat loss occurs at the building surface (especially window area), see figure 3.37.

![Figure 3.37](cold_winter_winds.png)

A larger building can also help create a low wind micro-climate to its lee side, but still suffers the consequences of blocking the cold wind (figure 3.38). Examples of the windscreen buildings are shown in figures 3.8, 3.15, and 3.16.

![Figure 3.38](low_wind_microclimate_area.png)
• Building Shape and Wind

Aerodynamic shapes with rounded corners help to reduce turbulence about the building surface decreasing the impact of higher winds, making the structure more stable in high winds (figure 3.39).

![Aerodynamic Shape]

**Figure 3.39**

• Building Orientation and Wind

As mentioned with the building shape, orientate the minimum building area perpendicular to the cold winter wind (figure 3.40). Blowing snow and potential snow drifting is even a more important implication for orientating the minimum area to the wind.

![Plan View](orientation-parallel-to-wind)

**Figure 3.40**
3.3.6 Special Climatic Conditions: Blowing Snow

<table>
<thead>
<tr>
<th>Reference Matrix</th>
<th>Climatic Factors</th>
<th>Site Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning Level 1</td>
<td>Solar Radiation</td>
<td>Topography</td>
</tr>
<tr>
<td>Planning Level 2</td>
<td>Temperature</td>
<td>Slope</td>
</tr>
<tr>
<td>Planning Level 3</td>
<td>Precipitation</td>
<td>Soils</td>
</tr>
<tr>
<td>Planning Level 4</td>
<td>Wind</td>
<td>Vegetation</td>
</tr>
</tbody>
</table>

- **Building Size and Blowing Snow**

  Larger buildings have the potential of producing larger snow drifts due to the greater area of reduced wind velocity created by the windscreen building. This causes the airborne snow to precipitate out on the lee side of the structure (figure 3.41).

  ![Figure 3.41](image)

  Much of these massive drifts could be eliminated by elevating the whole structure and letting the wind blow under the structure, clearing the snow from the downwind side.

- **Building Shape and Blowing Snow**

  Aerodynamic shapes tend to decrease the potential snow drifting as shown in figure 3.42, a snow drift analysis done for the BP Alaska/Sohoi's North Slope Operations Center at the Prudhoe Bay oil field.
Building irregularities on the basic building shape also affect the snow drifting potential as shown in figure 3.43.

Building Orientation and Snow Drifting

The amount of surface area perpendicular to the blowing snow (prevailing winds) to a large extent determines the amount of snow drifting which will occur.

Figure 3.44 shows the same building area, but orientation is changed so the building blocks more blowing snow. If the structure were elevated, the drifting becomes minimal as long as the wind has a chance to blow all the way through the underside of the building. In this case the increased surface area perpendicular to the wind/blowing snow still helps to increase heat loss, wind and snow infiltration, and stress on the structure as well as having a cold bottom when elevated and is therefore to be avoided.
3.3.7 Summary

The listing of planning objectives to be considered at planning level 2, building size, shape and orientation, are:

A. Solar Radiation
   a. Minimize solar shadowing through optimum shapes,
   b. Maximize solar radiation to housing units enclosed in large structures,
   c. Use interior vertical or sloped walls as thermal mass for solar heat collection,
   d. Avoid orientating housing units to the north with no other exposure,
   e. Use compact building forms orientated diagonally or if long, narrow building forms are used, orientate diagonally, or

B. Temperature
   a. Optimizing building size must take into account socio-cultural needs/expectations along with physical factors - a mix of sizes may satisfy the greatest number of inhabitants,
   b. Use compact building shapes: hemisphere, cube, and pyramid,
   c. Avoid building relief and articulation on the building exterior.

C. Precipitation
   a. Avoid snow slides off buildings onto areas which could be hazardous.

D. Wind
   a. Avoid buildings higher than the surrounding wind protection; vegetation, topography, and other buildings,
   b. In areas without potential snowdrifting, the building may break the wind for a more desirable micro-climate area,
   c. Have minimum surface area facing winter wind,
   d. Use aerodynamic shapes to lessen impact of the wind.
E. Special Climatic Conditions: Blowing Snow

a. Avoid large buildings when snow drifting can occur on the lee side,
b. Elevate structure to allow wind to sweep under clearing snow to leeward,
c. Use aerodynamic shapes to minimize impact of the wind,
d. Avoid building irregularities which would cause potential snow drifting,
e. Orientate the smallest building area towards the wind/blowing snow direction.

Within this listing of planning objectives there are conflicts which need to be resolved. The climatic region in which housing will be built normally determines the priorities needed to resolve these conflicts.

1. Building Size

● Extreme Environment (Arctic):

In this region there exists a conflict between the economic need for a large structure encompassing many activities and functions within its enclosed micro-climate (BP Alaska/Sohio's North Slope Operations Center, the 26 story pyramidal building in Norilsk, Russia) and the need to minimize the impact of the wind.

In the arctic region there is little vegetation or topography (along the North Slope) to help block the cold winds; so, no matter what the building size, the wind will have an impact on it - the building shape and orientation can help reduce the structural impact of the wind on larger structures. Blowing snow/snow drifting which normally accumulates around buildings (large or small) in the arctic region can be minimized by elevating the structure so that the winds can continually clear the lee side of the structure
of drifting snow. Limitations may occur for building sizes which become too large to be elevated above the ground.

• Less Extreme Environment (Sub-arctic):
  With the absence of blowing snow and constant cold winds, the exterior spaces are less hostile than in the arctic region. This factor leads to the building of more dispersed town facilities and housing instead of putting everything in a single enclosure which permits people to totally avoid the exterior natural environment. Smaller buildings in the subarctic can be shielded from winter winds by the forest cover and topographic characteristics.

Although wind and blowing snow are not major problems, the extreme cold temperatures in this region help to advance the argument for mega-structures which would be less costly to operate and maintain than a more dispersed, open townsite. The biggest problem with the megastructure type of townsite is its inability to take advantage of the beautiful natural environment which occurs during the summer. In addition, the compacted built environment (single building megastructure) could intensify social conflicts during winter since so much time is spent inside.

2. Building Shape

• Extreme Environment (Arctic):
  The greatest conflict which occurs is that of breaking the wind for a more desirable microclimate condition as well as having the wind continually clear wind blown snow in order to minimize snow drifts about the building. The elevated building allows the wind to blow under it, while clearing the drifted snow this solution negates any low wind micro-climate condition on the lee side of the building. The degree to which snow
drifting occurs varies throughout the Arctic. In some areas drifting can reach 15' to 20' while in other locations where precipitation levels are less, only 2' to 3' drifts occur. In locations where drifting is minimal, it would be advantageous to block the wind and help create a more pleasant exterior environment and use the drifted snow for insulation and recreation.

- Less Extreme Environment (Sub-arctic):
  In this region the major conflict lies in the optimization of heat loss and heat gain. Minimizing heat loss to the cold temperatures requires the use of compact building shapes while optimizing for solar heat gain means exposing more area to the direction with the most sun. It is suggested that a compact building form should be used with the orientation selected to maximize the solar radiation. Minimizing solar shadowing of buildings on each other and on exterior spaces also suggests the use of compact building shapes.

3. Building Orientation

- Extreme Environment (Arctic):
  Here again the conflict lies in the desire to block the wind in order to help create a more pleasant exterior environment or to minimize obstruction of the wind in order to keep snow drifting to a minimum. The selection of one parameter over the other would depend on the degree of snow drifting for the particular area along with the maintenance problem of having to remove excess snow accumulation.

- Less Extreme Environment (Sub-arctic):
  Orientation of buildings in the sub-arctic should be based primarily on sun and view. Some localized conditions may make wind protection
a dominant factor but over most of the region
the built environment should be located on south-
east, south, and southwest hillsides in order
to maximize winter, spring, and fall solar radia-
tion. In addition, housing units should not
have their only orientation to the north denying
them sunlight for most of the year.
3.3.8 References


2. Dr John Hay, Radiation Data for B.C. and Alberta, Geography Department, University of British Columbia, Vancouver, B.C., unpublished data analyzed by J. Ross


7. Hay, Radiation Data, analysis by J. Ross 1976-77


10. David Clunie, "Two New Northern Communities", Contact, August 1976, p. 311


13. Ibid., p. 168

15 University of Alaska short course, "Geodesic Domes", Ralph Mathews, instructor, taken by J. Ross 1974, College, Alaska
16 Ibid.
18 Ibid.
19 W. A. Dalgliesh, D. W. Boyd, Wind on Buildings, CBD 28, April 1962, Ottawa, Canada
20 Ralph Erskine, "Community Design for Production, for Publication, or for the People", RAIC Journal, Jan. 1964
21 Peter Floyd, "The North Slope Center: How Was It Built?", The Northern Engineer, Fall 1974, p. 28
22 P. A. Schaerer, Control of Snow Drifting About Buildings, CBD 146, Feb. 1972, Ottawa, Canada
23 Ibid.
24 Floyd, "The North Slope Center: How Was It Built"
### 3.4 Planning Level 3: Activity/Space Arrangement

<table>
<thead>
<tr>
<th>Reference Matrix</th>
<th>Climatic Factors</th>
<th>Site Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solar Radiation</td>
<td>Topography</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>Soil</td>
</tr>
<tr>
<td></td>
<td>Precipitation</td>
<td>Hydrology</td>
</tr>
<tr>
<td></td>
<td>Wind</td>
<td>Vegetation</td>
</tr>
<tr>
<td></td>
<td>Special Conditions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planning Level 1</th>
<th>Planning Level 2</th>
<th>Planning Level 3</th>
<th>Planning Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 3.4.1 Objective

This section is intended to point out building responses to the third level of planning (the activity/space arrangement) which help to improve housing habitability, lessen the adverse climatic implications, and maximize the desirable climatic implications.
3.4.2 Solar Radiation

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOLAR RADIATION</td>
<td>TOPOGRAPHY</td>
</tr>
<tr>
<td></td>
<td>TEMPERATURE</td>
<td>LANDSCAPE</td>
</tr>
<tr>
<td></td>
<td>PRECIPITATION</td>
<td>PLANNING</td>
</tr>
<tr>
<td></td>
<td>WIND</td>
<td>LEVEL</td>
</tr>
<tr>
<td></td>
<td>SPECIAL CONDITIONS</td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The great variation in solar radiation throughout the year has a major effect on the activities and space arrangements within the housing unit. Due to the limited winter sunlight, sunlight availability/penetration becomes very desirable during this period.

How important is sunlight in the home? A study of 939 housewives in Holland came up with some interesting conclusions:

"1. Practically all housewives wanted much light and sunshine in their homes. They attached great value to this.

2. As for the living-room, there was some preference for afternoon sun. Possibly, the insolation one actually had greatly influenced preferences for the insolation.

3. As for the kitchen and the bedrooms, there was a distinct preference for sun in the morning.

4. Most of the housewives shared the view that the insolation of the livingroom is the most important feature and, if necessary, they were prepared to sacrifice the insolation of the bedroom to ensure this.

5. A surprisingly high percentage (70%) of the housewives preferred an insolated room, without a fine view, to a room without sun but with a beautiful view." 

The farther north one goes, the greater the desire is to optimize winter sunlight, when available, since it is scarce during the cold months. Sunlight penetration is an important aspect of housing quality and at least one space (preferably the "livingroom") should receive sunlight sometime during the winter day."
Space arrangements may vary when trying to optimize sunlight for the varied seasonal conditions. During winter, sunlight is present only at the south side of a building provided it is not shadowed; during summer, sunlight is present at all orientations at some time during the long day. Activity spaces which most need winter sunlight should be adjacent to a south, southeast, or southwest side. By using second floor spaces (higher elevation), these activities will have a better chance of picking up direct sunlight than if they were on the first floor or basement level.

Should only daylight be needed, east and west orientations will have good light when the sun is high enough to reflect light off the snow cover and other objects to the east or west. The changing solar irradiation on exterior objects reflects varied light throughout the day; the east side receiving more morning to noon light and the west side receiving more noon to afternoon light. In northern exposures, reflected light seldom occurs during mid-winter due to most objects being in shadow (figure 3.45). When the sun is high enough to light objects to the north, the north side normally provides the best consistent indirect lighting reflected from objects (vegetation, buildings, snow cover) in constant sunlight most of the day.

![Figure 3.45](image)
Flexibility of the exterior skin can help the inhabitants to better adapt to the great seasonal variation in sunlight. The opening up of the building interior to the daytime views, sunlight, and solar heat could be a major design factor since the interior spaces should be closed off to the cold exterior during the long winter nights. Whole walls (insulated wall panels) could be moved to open up interior spaces onto sun heated daytime use spaces. Greenhouse type spaces could become part of the interior activity spaces during the days and be closed off at night to keep heat loss through the glass area to a minimum, see figure 3.46.

Such "buffer spaces" around the home unit would need to be orientated to the direction best suited for the time of day, time of year, and activity for which it would be used (figure 3.47). As an example, a space opening out to the west, northwest could be used for relaxing/entertaining/dining in the evening when the summer night air becomes cool making a glass enclosure heated by the afternoon sun a comfortable environment, but this orientation would have limited use during winter.

A space utilizing solar radiation during winter, spring, and fall could be opened out on the south orientation and be used for daytime activities - children's play area, planting, dining, and "living". A space to the south, when opened during a sunny winter day would allow sunlight and solar heat to penetrate the home interior.
TIME/LOCATION DIAGRAM FOR EXTERIOR USE
SPACE ADJACENT TO THE LIVING UNIT

Figure 3.47
3.4.3 Temperature

Temperature is important to locating activities/spaces such as entrances/exits as well as spaces which should or should not be adjacent to cold exterior wall surfaces. The inflow of the outside cold air also affects the thermal regime within the structure.

Doors to the exterior with high usage often have "arctic entries" (figure 3.48) which are normally transition rooms where the cold air from the outside will be blocked by the outer door when the inner door is opened. The two door system in the home does not always work as intended since people quite often use other entries with only one door which provides the access to transportation (autos) and children's play areas, while the "arctic entry" fills up with storage items.5
More important than the two doors in the subarctic region is the entry level when trying to keep out the cold air. When the entry is lower in relation to the heated interior, there is less heat loss when the door is opened since cold air stays low and warm air rises. If the entry was in the floor as done in some of the igloo designs (figure 3.49), the heat loss would be minimized.

This "trap door" arrangement (figure 3.50) is inconvenient for most people in the "modern" home so a lower entry level space is the next best thing (figure 3.51). This confines the incoming cold air to the lower floor area near the entry while keeping the outflow of warm air to a minimum.
Another example of this lower level entry was developed for Inuit housing in Arctic Quebec, see figure 3.52.

"A three-level house was developed to conserve heat. The furnace has located on the entrance floor on first level. The cold air, being more dense than warm, remains at the lower level. The warm air would flow by natural convection to the upper levels and force the cold air to the first level. The high winds of the Arctic necessitated an outside porch (arctic entry) as a transition to this lower level entrance. The porch forms a trap for the main thrust of the wind. The home owner would enter a general storage and mechanical area which would have only ambient heat of the furnace but no direct heat. This space would be cooler than the other two levels of the house."

Closing off rooms in a house causes temperatures to vary from space to space since the air is sectioned off. When closed off, heat generating activities (people, lights, appliances) have their heat restricted to smaller areas requiring ventilation of those spaces while others are cool. All closed off spaces would have to have their own heat supply which is most often regulated by one thermostat located in a central space. See figure 3.52 for unrestricted air flow example.
Another cold temperature implication is the effect of mean radiant temperature (MRT) heat loss from the body to cold interior surfaces. Exterior walls will have cool interior surface temperatures during the cold winters. In most cases the coldest surface will be a window which can be as much as 30 degF to 40 degF below room temperature. These surfaces cause a radiative heat loss from the body of a person. The person in turn will adjust the thermostat up higher to be more comfortable. This radiative heat loss can be lessened when the person is farther away from the cold surface since other interior surfaces (warmer) also have a radiative effect on the person.

Spaces near expanses of cold glass should not be used for sitting/relaxing since this is where the highest radiative heat loss will occur. Having activity and movement areas adjacent to the cold surfaces and areas for sitting/relaxing farther away will help counter the cooling effect of the surfaces (figure 3.53).

Other possible solutions include exterior shutters over windows to lessen the MRT effect by warming the interior surface temperature. Drapes or interior blinds can be used over windows (most common solution) but precautions must be taken to avoid moisture accumulation and icing on the window surface. Also, clothing helps to minimize this feeling of heat loss.
The long duration of winter, in conjunction with its cold temperatures necessitates the use of much cold weather clothing and equipment. It's important to provide adequate storage for this cold weather equipment. From parkas to "bunny" boots, snow removal equipment to skis, most of the equipment can be stored out in the cold or, as happens a lot, in the arctic entry or covered porch. Due to the high usage of interior space during the winter, it's important to have enough storage adjacent to the house to handle the wide variety of equipment. A space such as shown in figure 3.54 also provides a good buffer from the extreme cold exterior for the warm house interior.

Storage of frozen goods outside is also quite often done taking advantage of nature's deep freeze. Freezers themselves are often kept on cold porches or outside adjacent to the north side of the house. Some hunters who return with large amounts of moose or cariboo will keep it on top of the house, frozen and away from the dogs.
3.4.4 Precipitation

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLAR RADIATION</td>
<td>PRECIPITATION</td>
<td>TOPOGRAPHY</td>
</tr>
<tr>
<td>TEMPERATURE</td>
<td>WIND</td>
<td>GEOLGY</td>
</tr>
<tr>
<td>SPECIAL CONDITIONS</td>
<td></td>
<td>SOILS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CLIMATE</td>
</tr>
</tbody>
</table>

PLANNING LEVEL 1
PLANNING LEVEL 2
PLANNING LEVEL 3
PLANNING LEVEL 4

The use of exterior spaces during winter should figure on the utilization of snow cover. Snow mounds, hills, or drifts can be used for play, sledding, skiing, or even just sitting out in the sun. For optimum use adjacent to a housing unit, the space should receive direct sunlight since air temperatures are so low during much of the winter. Outside play areas adjacent to the house should be located on the south, east, or west side to maximize direct sunlight. Clustering of housing units should leave "sunlight corridors" into the play spaces for winter use, see figure 3.55.

![Figure 3.55](image-url)
Pedestrian entrances and exits as well as vehicular access should be located in order to avoid rain runoff and snow slides from the sloping roof, see figure 3.56.12

FIGURE 3.56
3.4.5 Wind

As mentioned before, the wind chill experienced by people is an important design factor when establishing the locations of the exterior play/rest areas and circulation spaces. The greater the wind velocity, the greater the heat loss from the exposed surfaces of the body causing discomfort and possible freezing (frost bite).

Location of the entry is also influenced by the prevailing winter winds. When a wind blows constantly against the exterior door, the two door arctic entry becomes more desirable since the transition space will stop the wind from blowing through the cracks around the interior door slowing the cold air infiltration, see figure 3.49. The outside door should not open directly toward the winter wind direction, see figure 3.57.

---

<table>
<thead>
<tr>
<th>PLANNING LEVEL</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOLAR RADIATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEMPERATURE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SPECIFICATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WIND</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SPECIAL CONDITIONS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOPOGRAPHY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GEOLOGY</td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 1</td>
<td>Wind chill</td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANNING LEVEL 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Figure 3.57**

ENTRY  

WINTER WIND DIRECTIONS

---
3.4.6 Special Climatic Conditions: Blowing Snow

In areas with potential snow drifting, avoid locating fenestration (doors and windows) where snow-drifting will make them useless such as on the lower portion of the lee side of the building (figure 3.58). In this case the house should have a second exit.

**Figure 3.58**
3.4.7 Summary

The listing of planning objectives to be considered at planning level 3, activity/space arrangements, are:

A. Solar Radiation
   a. Sunlight penetration is an important aspect of housing quality and at least one space (preferably the "living room") should receive sunlight sometime during the winter day
   b. Spaces requiring sunlight should be located on the southeast, south, or southwest portions of the structure as high as possible
   c. Areas requiring good daylighting should avoid the north side during winter
   d. Provide flexibility of space - open up housing unit to "daytime spaces" located southeast to southwest

B. Temperature
   a. Locate entry to housing unit at a low level
   b. Allow interior heated air to circulate freely to all areas requiring heat at each level
   c. Minimize body radiant heat loss to the cold surfaces of exterior walls/windows by keeping inactivity spaces away from surfaces
   d. Adequate space for cold storage should be provided - if in the entry way the entry space should be much larger than the typical arctic entry

C. Precipitation
   a. Use snow for play areas on south side
   b. Location of entries/exits and garage openings should be protected from rain, snow, and potential snow slides off the roof

D. Wind
   a. Exterior activity spaces should be protected from winter winds which increase wind chill factor
b. Location of entrance/exits and interior openings should not face winter wind direction

E. Special Climatic Conditions: Blowing Snow
   a. Avoid locating fenestration (windows, doors) where snow drifting will make them useless

Areas with wind and blowing snow (arctic region) have difficulty achieving desirable south facing exterior use space which is not covered with snow drifts (especially on the North Slope where wind comes from the northeast) or subject to constant wind. In addition, the change in solar azimuth travel is so rapid (from no sun to 24 hours of daylight) in only a few months that east or west orientations could have nearly equal importance as the south orientation with regard to solar radiation. In this case protection from the wind becomes a first priority.
3.4.8 References


2 James Wechsberg, "Morketiden," New Yorker, March 18, 1972

3 "When the House-Warming Sun Goes Down, Movable Insulation Goes Into Place," Sunset, Nov. 1976, pp. 166-168

4 Based on the sunpath diagram constructed by the author for 62° north latitude, see Appendix A

5 Burgess Ledbetter, "The Temporary Environment of Fort Wainwright, Housing Part II," Cold Regions Research Engineering Laboratory (CRREL), Hanover, N.H., unpublished 1976

6 Eb Rice, "The Ideal Arctic House - II," The Northern Engineer, Summer 1973, p. 19


8 Leo R. Zrudlo, "User Designed Housing for the Inuit of Arctic Quebec," The Northern Engineer, Fall 1975, p. 40


10 Burgess Ledbetter, "The Temporary Environment"


12 Boris Culjat, Climate and The Built Environment in The North, Arkitektursektionens tryckeri, KTH, Stockholm, Sweden, 1975

13 Rice, "The Ideal Arctic House - II," p. 19

14 Ibid., p. 23
3.5 PLANNING LEVEL 4: DETAILING OF THE BUILDING FABRIC

This section is intended to point out building design responses at the fourth level of planning (the detailing of the building fabric) which help to reduce the influence of adverse climatic effects, and maximize the desirable climatic effects.

Selecting the materials within the building fabric as well as its placement becomes most noticeable over time when a mistake has been made. If no mistakes are made then the "good design" goes unnoticed and the house can "work" like any other house in a lower latitude with a more moderate climate.
Solar radiation has an influence on the make up of exterior walls and the surface shade/color of the exterior skin of the building. The greatest influence is on the window area; the amount of window area, the location of window area, and the control of the sun and glare at the window surface. These factors control housing unit heat loss, heat gain, amount of natural lighting, and visual discomfort. The surface shade/color also influences the housing units heat gain and heat loss as well as thermal stresses in the exterior skin.

- **Amount of Window Area**

The window area on the exterior envelope should be kept to a minimum (normally around 10% of the floor area) primarily due to heat loss during the cold months (see 3.5.3 Temperature for more detail). From late February till early November the prospects of utilizing solar heat gain are good since the midday solar altitude is above 10° and the increased azimuth travel makes solar heat gain available to more than south facing orientations. If window area is limited due to heat loss during the winter, then it becomes more difficult to optimize for solar radiation during the spring, summer and fall. During those periods the daylight and view are
available for longer periods and the sun's radiation can help heat the house interior, the penetration of sunlight is desirable and more window area becomes an asset.

Several approaches can be taken to "solve" this problem. The first and the most widely used for many years was to get out of the house when it was pleasant outside. In this way the homes were more "dens" for hibernation in the winter than year round living environments. A second approach is to have a house with large window areas so one is in constant contact with the exterior environment, but this solution has high operation and maintenance costs. A third approach is to have a house with a flexible exterior skin; parts of the house could be opened up in good weather in order to let light, view, and heat into the space and closed off thermally during cold periods minimizing heat loss.2

Insulated panels could serve as "walls" on the east, south, to west sides which could swing open allowing:

1. a thermal mass or interior objects and people to absorb direct solar radiation,

2. views of the outdoors, and

3. an abundance of natural light.

Incorporating this flexibility into an overall shape, it is still possible to minimize the building's exterior skin surface area as well as provide glass windows/walls with movable insulated panels as shown in figure 3.59.

The opening and closing of the home would be much like a plant or flower which opens to let in valuable sunlight when available and closes when it becomes dark and cold.
Location of Window Area

When window area is kept to a minimum, sunlight is at a premium and must be optimized with regard to view and illumination. View characteristics include the near site (vegetation, birds, and animals, natural elements - rainfall and snowfall), the middle distance (other homes, people, streets, autos), and the distant view (mountains, valleys, clouds, city lights). A view is a personal preference and each user will give his own priority to the view his particular site will allow.
To look at a view or activity outside usually means the use of a bay window or something similar which is large, low, and centered in a space (figure 3.60).

![Figure 3.60](image)

When placing windows for optimum illumination, the bay window centered in the room is one of the last choices. Vertical strips of window adjacent to an interior wall or horizontal window strips near ceiling level bring in light which washes the walls and/or ceiling with light which increases the room illumination (figure 3.61). This method depends on the brightness and reflectivity of the walls and ceiling surfaces, a light shade of most colors increases the luminance and illumination on a working plane.

![Figure 3.61](image)

Since natural light and view both compete for the same limited window area, we should ask which is most important during the winter months when the light availability is so short, and are there ways to combine the two uses? The answer to the first question is not
simple since it may differ for each individual user. Optimizing the window placement for natural light may frustrate some people because they cannot view out so easily while for others this arrangement may not bother them.

Ways of combining the two uses have been attempted in cold climate areas for quite some time:

1. Lower the horizontal window band so that one can view out while standing (figure 3.62),

2. Widen the vertical window band near the wall so a view can be enjoyed while sitting (figure 3.63),

3. Use of corner windows - light can be reflected on either wall increasing illumination and the view angle is greatly increased with no obstructions where the windows meet at the corner (figure 3.64),
4. Open up wall panels to sunlit spaces for daytime use - the sunlit space may not be warm enough to use in mid-winter yet window area may be in the movable panels for light and view (figure 3.65).^{

Skylighting can be very useful in the northern environment. Skylights/ clerestory windows can be positioned to bring light into the building interior better than the vertical wall windows. They also provide the light to the upper floor space or quite often into an interior space which is open to several floors, providing natural diffuse lighting to the central interior.

The shape of a building which responds to the sub-arctic climate with a minimum of surface area creates larger interior spaces which are farther from the light/sunlight sources on the exterior walls (figure 3.66). In small structures such as moderate sizes homes, this may not be so noticeable as in a larger building in which the interior can be lacking natural light. Skylights can be used to supply natural light to these areas.⁹
Skylights and clerestory windows can also bring south light and sunlight to the north side of the home during winter by the positioning of these windows (figure 3.67).

![Figure 3.67: Winter Sunlight through Skylights and Clerestory Windows]

Skylights can also be used as sunlight reflectors. Reflective skylights can pick up low sunlight and direct it into the building interior (figure 3.68).  

![Figure 3.68: Reflective Skylights]

Being able to pick up the sunlight from the building roof level helps to capture low angle sunlight plus reflected light off the roof (snow) during winter and spring (figure 3.69).

Closing the skylight off with an interior glass pane can help reduce heat loss, but the inside pane should be sealed to avoid moisture migration to the outer glass pane (figure 3.69). 

![Figure 3.69: Reflective Surfaces]
The window location can also influence its heat loss potential. For the exposed window/skylight, the more it is angled towards the horizontal, the more it:

1. radiates heat (loss) to the atmosphere;
2. allows less winter (low angle) sun penetration;
3. allows more sun penetration during the summer months (figure 3.70).

In areas with appreciable winter winds the sloping window surface would help to reduce the force of the wind on the surface.

During the winter the skylight with minimal slope would collect snow which would melt to ice due to the heat loss through the glass. This normally causes large icicles to form (figure 3.71).

---

**Figure 3.70**

**Figure 3.71**
Sun/Glare Control Through Window Area

During winter, snow covers most horizontal surfaces and sloping roofs. Since snow reflects much of the light which strikes it, high illumination levels as well as glare can be experienced in the home.

"Direct sunlight falling on a bright surface can cause glare with attendant visual discomfort unless the level of illumination in the other parts of the room is not too different from that of the sunlit areas." 12

The low winter sun angle helps to produce two major sources of glare:

1. the reflection of sunlight off interior objects,
2. the reflection of sunlight off snow on the exterior.

The first type of glare can be bothersome from anywhere in the room when the reflecting surface appears bright in relation to the rest of the room. The second type can "blind" the person when looking out the window when the eyes are adjusted to the interior lighting level (figure 3.72).

Solar penetration and glare can be controlled by exterior shading, glazing types, interior shading, and the location of fenestration. Interior shading, curtains, shades, and blinds, can cut down on the light, but they normally block the view. Also, they can cause moisture/icing problems on the windows during the cold months which is discussed in another section. Exterior shutters can eliminate the moisture/icing problems if moisture does not leak from the window causing the operating mechanism to ice up.
Exterior Shading

Shading by the building exterior such as overhangs are generally ineffective for several reasons. Overhangs block south facing summer sun to a limited degree, but also block skylight from coming into the room interior through vertical windows, reducing the room illumination (figure 3.73).

If the roof assembly is a "hot roof" the overhang is normally colder than the rest of the roof so any snow melt from the main part of the roof will freeze on the overhang causing massive ice dams during winter and spring.
Exterior shutters (insulated, movable panels) have a variety of uses in the diversified northern conditions (figure 3.74). 15

Winter
Keep warmth in and cold out

Early Spring
Reflected sunlight into interior

Spring/Fall
Allow sunlight penetration and reflect sunlight on adjacent exterior use space

Spring/Fall or Summer East/West
Restrict sunlight penetration

Summer Nights
Block unwanted sunlight and allow for ventilation

Summer Days
Control sun penetration protect/cover window during bad weather

The use of exterior insulated shutters is not widely spread in the Alaskan urban areas, but I can relate how two different families in Fairbanks, Alaska, manipulated their own environment with movable insulated shutters on the outside of their windows. The original purpose of the shutters was to reduce the
heat loss through the glass window area. This normally required opening the shutters in the morning and closing them after sunset during the cold months. One family did exactly that, while the other used the shutters for sun shades on their south facing windows not bothering to close them every night. They both closed the shutters when away from the house for several days or more. While the shutters may not have been used as originally intended by both residents, the option was there for the individual to use the shutters as he wished providing flexibility depending on the person's priorities and energies; in the one case solar shading was more important and less bother than controlling heat loss.

The flexibility of use in this case was perhaps even more important than reducing heat loss since each family was able to enhance the livability of their environment through the use of the shutters.

Shading By Glazing Type

Solar absorbing and reflecting glass could be used to decrease both heat and light. Solar control by the use of window glass has its own special problems. Clear float glass (double glazing- thermal pane) will normally transmit around 80% of visible light and 70% of solar heat. Tinted and/or reflective glass is normally used to reduce the solar heat during summer conditions. In a home and especially in a cold climate where window area is minimized, solar reflecting/absorbing glass is not necessary since the absorbing glass reduces the radiant heat transmittance to around 35% and visible transmittance to around 40%. Reflective glass has even lower values, 25% for both heat and light. Since most of the year we are trying to maximize solar heat and light, these types of glass would only be usefull during the spring and summer. They could be utilized as a movable shutter to help cut down glare and unwanted summer sunlight, see figure 3.75.
Interior Shading

A shade or curtain of some type over the lower portion of the window area (up to about 5 - 6 feet) will cut down both types of glare by confining the brightness to the upper window area where the reflected light from the snow will light the ceiling and the direct sunlight will penetrate deeper into the room reducing interior glare probability (figure 3.75).

Since a major criteria for window shading is the achievement of privacy, the interior blinds, curtains, or shades are best suited for this purpose due to ease of handling. Interior shading devices need to be positioned correctly (see Temperature Section), or the windows could become covered with ice providing little or no view from either side.
Control By Fenestration Location

High windows keep the reflected glare from snow out of view and spread the high intensity light onto the ceiling which helps to brighten the entire room. Direct sunlight penetrates deeper into the room from high windows. East and west facing windows are especially susceptible to glare in spring when the sun's altitude is relatively low in the east and west and the ground is still covered with snow. Orientations from south to west are the most critical due to winter and spring sun location/altitude and the time of day certain spaces are most used. In greenhouse type spaces glare becomes less of a problem due to the overall high illumination level within the space. Skylights are less of a problem than vertical windows since they normally provide upward views and when the sun penetrates, it is at a higher altitude, see figure 3.76.

![Figure 3.76](image-url)
Surface Shade/Color and Texture of the Exterior Skin

"With few exceptions, color, as such was found to be non critical with regard to temperature characteristics. However, shades of light and dark were extremely important." ¹⁷

Another means of control or use of solar radiation is through the use of shades of light and dark surfaces. Since high heat gains are experienced in dark surfaces (as much as 90°F above ambient air temperature) and only moderate heat gain in light or reflective surfaces,¹⁵ the building surface should be evaluated as to:

1. time of day of the greatest solar radiation,
2. time of year it is exposed to solar radiation,
3. amount of time exposed to clear night zenith,
4. watertight integrity desired (minimize freeze/thaw cycles).

Dark surfaces which receive solar radiation will have more solar heat gain, more night radiation heat loss (greatest toward zenith), more thermal stress on materials (exterior skin), and more freeze/thaw cycles than a light surface.²⁰

Each of these factors has varying importance depending on the orientation of the surface. A horizontal or roof surface which receives its maximum solar radiation at midday during the warmer months of the year (mid April through mid October) would normally require a light colored surface. This also holds true when a high degree of watertight integrity is essential since high thermal stress and freeze/thaw cycles work against the materials ability to remain watertight.

One other factor to be considered is the outgoing nighttime radiation. Since a roof is the closest surface orientated to the sky's zenith, it will experience the most radiative heat loss during clear cold, dry nights. A dark surface (black body) will increase this heat loss to its maximum at a time when the heat is most desired in the home. So, once again a light colored roof surface would be preferred since it would
reduce this heat loss during the night (figure 3.77). During the coldest months of the year, October through April, the roof is normally covered with snow which will negate the effect of roof surface shade or color.

![Diagram of a roof with text: Minimum horizontal roof area. Use light shade/color on horizontal roof.]

**Figure 3.77**

Vertical surfaces are:
1. not exposed to the clear night's sky zenith;
2. not required to be as watertight as a flat roof; and
3. receive solar radiation at different times of the day and at different times of the year depending on the orientation.

Due to these factors it becomes more advantageous to select a dark surface (for thermal mass materials) for certain orientations which can collect the solar heat during cooler periods. The south, southeast, and south-west orientations are best for this during winter. Solar radiation becomes available on the northeast, north, and northwest orientations during the late spring and summer months when temperatures are milder. These orientations could capture the solar radiation when the sun angle is low in the mornings and evenings, helping to balance out the cool nighttime temperatures.21

The east and west elevations are more of a problem. During the summer, the sun is at an altitude of 25° to 30° when perpendicular to the east and west orientations producing a fair amount of solar heat gain. In the morning this heat could be used to eliminate the morning chill, yet would be undesirable to be stored up in a thermal mass only to be reradiated
during the warmest part of the day. So, the east orientation should have light surface colors for both the exterior skin and any thermal mass which the sun might strike. In this way the solar heat can be used directly, limiting the storage of it in the building structure. For the west orientation, the use of thermal mass is advantageous since it will help warm the cool evening air.

A dark surfaces thermal mass may tend to overheat that side of the house at times. Possibly the best solution here is to have movable panels or shutters which have a light exterior surface so that when solar heat is wanted these can be opened in order to heat the interior. When solar heat is unwanted, they can be closed, exposing only the light exterior surface which will not absorb as much solar heat. For more information on thermal stresses, see the next section on Temperature.

Exterior Skin Texture

Smooth surfaces tend to be more reflective with rough surfaces being less reflective, having a higher absorption and dispersion of light. Light colored surfaces reflect more light while dark colored surfaces absorb more light. So, a light colored smooth surface will have the highest glare potential. In the housing unit interior, light, textured ceilings are quite often used because the light color distributes more of the reflected light, and the surface texture diffuses it more, minimizing glare while maximizing the light. Floors would have least glare when dark and slightly textured. This may be desirable since the glare potential is high from the low angle direct sunlight hitting the floor surface.
3.5.3 Temperature

The very cold winter temperatures along with the great variation in seasonal temperatures strongly effects the make up of the building fabric. It's important to minimize the implications due to large temperature differences between the building interior and the exterior with regard to:

1. Heat loss
   a. Make up of exterior skin - thermal mass versus the insulated frame structure,
   b. Optimal thermal insulation for walls, floors, and ceiling/roof,
   c. Control of fenestration heat loss,
   d. Minimize infiltration/air exchange heat loss,
   e. Limit frost penetration in the building interior.

2. Thermal bridging: minimize conduction of cold temperatures through the building materials (cold spots on the interior) which accumulate moisture and often have an ice build up.
   a. Minimize cold penetration by the arrangement of the building fabric such as enclosing the structural system with an insulating skin,
   b. Use of thermal breaks.
3. Material thermal stress, expansion and contraction
   a. Care in placement of adjacent materials,
   b. Control impact of solar radiation on building skin temperatures,
   c. Minimize loss of material strength and deterioration.

Heat Loss

The importance of minimizing building heat loss is especially critical in the northern areas since the cost of heating a home throughout the long cold period can be very high. Figuring the heat required based on the heating index (° days), a home in the Susitna Valley in Alaska would need approximately 40% more heat than a comparable home in the Minneapolis area (110% more than a comparable home in the Vancouver area) in order to maintain the same interior temperatures.

In order to minimize the heat loss, first, it becomes necessary to identify and quantify the major heat loss paths. Figure 3.78 shows the relative order of magnitude of different components of the total heat loss in an "average" dwelling. Most of the heat is lost through the walls and from ventilation and infiltration. Since a "tight house" built in the north normally keeps the cold air infiltration down to about \( \frac{1}{2} \) air change per hour or less, the largest single contributor to heat loss is the fenestration (windows and doors); taking up only 9% to 20% of the wall area, they account for 35% to 60% of the heat loss attributed to the walls.
### FIGURE 3.78

% HEAT LOSS OF ELEMENTS OF THE HOUSE

<table>
<thead>
<tr>
<th>Reference</th>
<th>Ceiling</th>
<th>Walls (inc.doors &amp; windows)</th>
<th>Floor (congrade)</th>
<th>Ventilation &amp; Infiltration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ASHRAE 24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detached &quot;Bungalow&quot;</td>
<td>13%</td>
<td>60%</td>
<td>5%</td>
<td>22%</td>
</tr>
<tr>
<td>2. HUDA 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Bungalow (1080 ft²)</td>
<td>17%</td>
<td>54%</td>
<td>3%</td>
<td>26%</td>
</tr>
<tr>
<td>b. Split-Level (1107 ft²)</td>
<td>14%</td>
<td>54%</td>
<td>3%</td>
<td>24%</td>
</tr>
<tr>
<td>c. Semi-Detached (1080 ft²)</td>
<td>12%</td>
<td>60%</td>
<td>2%</td>
<td>27%</td>
</tr>
<tr>
<td>d. Row House (1080 ft²)</td>
<td>14%</td>
<td>51%</td>
<td>1%</td>
<td>33%</td>
</tr>
<tr>
<td>3. Steadman 26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detached &quot;Bungalow&quot;</td>
<td>13%</td>
<td>42%</td>
<td>5%</td>
<td>40% (1 air change/hour)</td>
</tr>
</tbody>
</table>

% HEAT LOSS IN WALL ELEMENTS

<table>
<thead>
<tr>
<th>Bldg. Type (% of wall area is windows &amp; doors)</th>
<th>Exterior Walls</th>
<th>Windows</th>
<th>Doors</th>
<th>Decreased heat loss by bldg. type: % Less</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. HUDA</td>
<td></td>
<td></td>
<td></td>
<td>Below Grade Basement Walls</td>
</tr>
<tr>
<td>a. Bungalow (9%)</td>
<td>28%</td>
<td>28%</td>
<td>7%</td>
<td>37% Data Base</td>
</tr>
<tr>
<td>b. Split-Level (13%)</td>
<td>28%</td>
<td>34%</td>
<td>8%</td>
<td>30% 16% Less</td>
</tr>
<tr>
<td>c. Semi-Detached (11%)</td>
<td>35%</td>
<td>35%</td>
<td>8%</td>
<td>22% 25% Less</td>
</tr>
<tr>
<td>d. Row House (20%)</td>
<td>24%</td>
<td>49%</td>
<td>11%</td>
<td>16% 39% Less</td>
</tr>
<tr>
<td>2. Steadman</td>
<td>36%</td>
<td>64%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Decreased heat loss by bldg. type: % Less
Make Up of Exterior Skin - Thermal Mass verses the Insulated Frame Structure

Is a building with high thermal mass, built in concrete, brick, stone, or even logs, better for the north than the light weight insulated frame structure? High thermal mass is usually associated with a heavy heat retaining material such as those listed below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Time Lag in Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>8&quot; concrete</td>
<td>5.1 hours</td>
</tr>
<tr>
<td>8&quot; stone</td>
<td>5.5 hours</td>
</tr>
<tr>
<td>8&quot; brick</td>
<td>5.5 hours</td>
</tr>
<tr>
<td>8&quot; wood (extrapolated)</td>
<td>5.2 hours</td>
</tr>
</tbody>
</table>

The advantage of a building with high thermal mass is that the heat from the daytime is stored in the mass and released at night when the outside air is colder. This effect balances the diurnal temperature differences within the house interior when the exterior temperatures may vary as much as 50°F to 60°F. Since the diurnal temperature changes are small during the long winter with little solar heat input during the day, the high thermal mass house will be constantly losing heat, day and night, if its R value (resistence to heat flow) is less than the insulated frame house. A 2x6 stud wall (stud spacing 16" on center) filled with insulation has less than ½ the heat loss of a wall made of 8" diameter round logs (figure 3.79).

Because of the high thermal mass, once a log cabin is heated it returns the heat from the logs for quite some time. This is important to those people in the north whose evening fire warms the cabin before going to bed and the logs reradiate the heat back during the night so that temperatures are not 20° below zero by morning. Homes in the north which have some type of mechanical heating system which keeps the interior within the temperature range of 55°F to 75°F will be less expensive to operate with walls.
which have the least heat loss instead of one with high thermal mass and higher heat loss.

Thermal mass could be used to best advantage when done in conjunction with the greenhouse effect. Since the outside air temperatures are cold even during the day, the thermal mass could be on the interior of the house facing the sun, collecting the solar radiation in the fall and spring (figure 3.80).

![HEAT LOSS COMPARISON](image)

**Figure 3.79**

Similarly, a thermal mass could be used on the exterior wall with an insulated wall panel over the outside of the mass which slows heat loss and can be opened when solar heat collection is desirable on the thermal mass. 31
The thermal mass of the earth can be used to the advantage of a housing unit. A basement which puts heat out into the earth will eventually (2 to 3 years) develop a heat bank in which the earth will take very little of the basement's heat and should the house heat go off, the earth will conduct the heat back into the house. One precaution must be taken and that is to insulate the earth from the cold winter air temperatures. This can be done with rigid insulation under the ground surface (figure 3.81).
Optimal Thermal Insulation for Walls, Floors, and Ceiling/Roof

When using high heat flow resistant materials such as insulation to retard the heat loss from going from the warm interior to the cold exterior, how thick should the insulation be? To figure this out certain information must be obtained for the area to be built in:

1. Heating Degree Days (° Days),
2. Cost of materials,
3. Cost of labor,
4. Cost of fuel,
5. Mechanical system efficiency, and
6. Amortization period.

Figure 3.82 plots the cost of heat with the cost of labor and materials. The low point in the sum of the two graphs gives the optimum amount of insulation for the area considered.
In walls, the insulation is restricted by the stud size, \(3\frac{1}{2}''\), \(5\frac{1}{2}''\), and \(7\frac{1}{2}''\) for 2x4s, 2x6s, and 2x8s. The cost of going from one stud size to the next larger size adds to the material costs roughly 20 to 30% at each jump. In the walls, \(7\frac{1}{2}''\) (2x8 studs) appears more economical than \(5\frac{1}{2}''\) (2x6's) on the graph but this may change depending on the actual cost jump for going from 2x6 studs to 2x8 studs. It's more critical here to point out that 2x4 stud walls, even when filled with \(3\frac{1}{2}''\) of insulation, are inadequate and will be more costly in the long run than 2x6 and 2x8 stud walls.

Since ceiling insulation is normally not installed in confined cavities, a thicker insulation can be used such as the 9" or more with very little added material cost.

Floor insulation need not be so thick since a minimum of heat loss occurs through the floor, the horizontal dead air space just under the floor acts as an efficient insulator, and the underfloor crawl space (closed) stays warmer than the cold outside temperature. Normally 2" of insulation with a dead air space between the insulation and the floor is sufficient for both comfort and minimum heat loss (figure 3.83). Should the underfloor space be used as an air plenum, then the insulating values of the dead air space are lost and more insulation would be required (6"). When floors are constructed over open crawl spaces which reach outside temperatures, a minimum of 6" of insulation should be used for comfort; when it's \(-40^\circ F\) outside, the interior floor surface temperature is about \(66^\circ F\) as opposed to \(60^\circ F\) with 2" of insulation (figure 3.83).
One situation encountered when the floors are too cold (insufficient insulation) is for the resident to nail up plywood skirting around the open air space under the house. This makes the floors warm and the crawl space warmer also. The problem occurs after a winter or two when the ground begins to shift under the building. In areas of permafrost, the closed in crawl space will eventually begin to melt the permafrost under the building causing differential settlement or even building collapse. 35
Control of Fenestration Heat Loss

Limit fenestration or control heat loss from windows with exterior insulated shutters. Double and triple glazing help reduce heat loss considerably over single glazing especially in a wind as shown in figure 3.84a. The dead air spaces (¼" to 1" optimum) between the glass panes give the window its insulating qualities against the cold temperatures. As shown in figure 3.84b, the use of insulated shutters can help much more than adding more panes of glass. The manual functioning of the shutters on a daily basis becomes the weakest part of this solution since it's up to the user to open and close them.

**HEAT LOSS COMPARISON (W/15 MPH WIND)³⁶⁰**

1. WINDOW HEAT LOSS W/O SHUTTERS

   ![Diagram](attachment:image1.png)

   - R=0.9
   - 25x
   - HEAT LOSS/SQ. FT.

2. WINDOW HEAT LOSS W/SHUTTERS (2" RIGID INSULATION)

   ![Diagram](attachment:image2.png)

   - R=14.9
   - 1.8x
   - HEAT LOSS/SQ. FT.

   - R=18.4
   - 1.2x

   - R=22
   - 1x

**FIGURE 3.84**
- Minimize Infiltration/Air Exchange Heat Loss

Minimize the heat loss at openings due to infiltration. This can usually be handled by weather-stripping around windows, doors, and other openings, and using louvers or dampers over air intakes. Dampers on stacks, one near the top (insulated) and one near the bottom reduce cold air penetration and the drawing of warm air out of the building interior. 37

Fireplaces can draw a lot of warm air up the chimney when burning. Normally the combustion air comes from the warm interior space causing more cold air to infiltrate into the building as well as causing a draft along the floor in front of the fireplace. 36 A special combustion air duct from the outside directly to the fireplace firebox can reduce this effect (figure 3.85). The louvered duct can supply the fireplace with its combustion air from the outside and be closed off when the fireplace is not in use. 37

![Diagram of a fireplace system with combustion air duct and dampers](attachment:image.png)
When trying to minimize cold air infiltration around windows, one of the most difficult to make tight is the sliding glass door. These should be used very sparingly to the outside since they experience high heat loss. Many windows in a home are operable, meaning they can be opened and closed to regulate air flow and ventilation. In figure 3.86, casement and awning type windows would be preferred over double hung and hopper type windows since the double hung has more cracks to let heat and moisture escape to the outside or to a storm window where the moisture could freeze, and the hopper type window will bring in rain or snow when opened if not sufficiently protected by an overhang.

The function of a window (light, sunlight penetration, views) can be separated from the need to ventilate the space. A mechanical ventilating system would be too expensive for the home, but wall openings (independent of the windows) in strategic places in exterior walls could be used for summer ventilation and become an insulated part of the wall in the winter (figure 3.87). Using this method for ventilation, the windows could be sealed and remain inoperable minimizing air and moisture leaks to the exterior.
Minimize Heat Losses Due to Air Exchanges

Since air exchanges pose the highest heat loss problem, it's most important to reuse the heat from the existing interior air. In larger buildings heat exchangers and heat recovery wheels are used to extract the heat from the exhaust air and transfer it to the incoming air.42 In the home a simplified version of this heat exchange can take place. "Buffer spaces" such as attics, underfloor, and storage spaces along exterior walls can be used for drawing in fresh outside air. The cold air enters the buffer space and warms to an intermediate temperature before it enters the house, see figure 3.55 and figure 3.88.

Another method is air filtering and redistribution. Have a fan in a high location in the housing unit suck the warm air down to the basement level, through air cleaning and moisture reducing filters. The redistributed air can then rise again through the interior spaces. "Dirty" air from kitchens and bathrooms can be vented directly to the outside so that the air cleaning filters would not have to cope with the more difficult odors, greases, and high moisture content, see figure 3.88.43
Use of a 'stack robber' (see figure 3.85) on a fireplace chimney or heater exhaust duct can extract heat from the hot stack or duct, heating interior air at upper levels.\textsuperscript{44}

- Limit Frost Formation in the Building Interior

The closing off of smaller spaces adjacent to exterior walls can cause freezing problems. Bookcases, closets, cabinets, plumbing chases, air ducts, and even windows behind curtains or shutters can experience condensation, frost, freezing pipes, and items frozen to the wall surface (figure 3.89a).\textsuperscript{45} These small air spaces (especially the area next to the exterior wall) need to be well ventilated with the interior warm air so that the wall surface does not reach dew point or frost point. The use of louvers in cabinet and closet doors or the elimination of the doors helps warm air to circulate better through these spaces. With the exception of the windows, most of these small spaces can be moved to the building interior away from the exterior wall. This is especially important for pipe chases since freezing pipes can cause a lot of damage.
Windows present a unique problem. Covering the interior glass surface with a curtain, blinds, or shutters can cause the air space between to act like a dead air space between window panes. The space will cool, allowing the inside glass surface to reach dew point temperature or even frost point temperature (figure 3.89b). By placing heaters or forced air registers under the windows or between windows and curtains/shutters, the air space can have air movement and heat which keeps the window surface warm. Another solution is to have insulating panels which cover the window on the outside and the elimination of interior coverings.
Inside corners can also have frost problems due to reduced air convection that lowers the surface temperatures in conjunction with more studs and less insulation (figure 3.90a). Corners could be rounded to reduce this effect; more insulation could be applied to corners, or heaters or fans could be installed closer to corners in order to increase the air convection currents (figure 3.90b,c).

**COLD CORNERS**

![Diagram of cold corners](image-url)

**A** Typical Corner

**B** Rounded Corner

**C** Insulated Corner

**Figure 3.90**
**Thermal Bridges**

Limit the conduction of cold temperatures through building materials. Conduction of the cold exterior temperatures into the building interior through a thermal bridge increases building heat loss. This problem is minor compared to the others created such as moisture and ice formation, thermal stress with adjacent materials, deformation, and movement.

- **Minimize Cold Penetration By Building Fabric Arrangement**

On larger buildings many problems can be eliminated by applying the insulation over the entire exterior surface keeping the structural components in the heated portion of the building. This helps to retain heat in the thermal mass of the structure, eliminates structural thermal bridges to the exterior, and reduces the expansion and contraction of the structural materials since they are not exposed to the winter extreme temperatures (figure 3.91).
Any metal which extends from the cold exterior to the warm interior can cause problems. Metal window frames, door frames, thresholds, metal structural connectors (bolts, fasteners), metal structural members (joists, decking, columns), roof drains, and air ducts all have low resistance to heat flow. Several solutions can be used. The item can be insulated as it enters the heated space such as is done with roof drains (figure 3.92) and air ducts, or the item can incorporate a thermal break unit so the material does not conduct the cold into the interior. Thermal break metal window frames and thresholds as well as the use of wood instead of metal can minimize the problem in these cases (figure 3.93).
One of the most common thermal bridges in the home is a nail driven into a 2x4 exterior wall stud from the inside. The nail, having a high conductance, transmits the cold temperature near the outside end of the stud to the warm interior space. Here the cold nail head, covered with wall paper or painted over, will collect moisture on which small amounts of dirt will accumulate over time. It is not uncommon to be able to count all the nails in a wall due to the small round dark spots visible on the walls. Use of thicker studs (2x6) normally eliminates this problem, but this points out one of the major problems with thermal bridges - the collection of moisture on the inside surface which can collect dirt or experience ice build up.

Deformation or movement can occur when moisture freezes on the cold surface. If sufficient moisture is in the air, ice build up can occur forcing adjacent materials to deform, break off or move away from the cold surface.

Heat can also flow from the inside to the outside along a thermal bridge where it can melt snow which will freeze forming ice on exterior surfaces. Window frames can freeze shut if snow is melted at the sill (figure 3.94), louvers can freeze open or shut, roof drains can freeze solid with ice, doors can freeze open (or closed) when ice accumulates in the hinges.

---

**Figure 3.94**
Minimizing the adverse effects of material expansion and contraction is important since deformations and separations/cracking can take place in building materials resulting from changes in temperature. Most materials expand when heated and contract when cooled. In the north, materials can experience temperature extremes of over 230°F due to the cold winter temperatures and solar heat absorption on dark surfaced materials. Each material moves different amounts under these extreme conditions having their individual coefficient of thermal expansion.

A comparison of different expansion/contraction coefficients shows normal dense concrete moving twice the distance brick, marble and dense limestone would move; steel, 2 1/3 times; copper, 3 1/3 times; aluminium, 4 2/3 times; and plastics ranging from 7 to 36 times. Structurally most metals can take the movement with little problem, yet concrete could fail in tension if not properly designed with "temperature steel".

The materials ability to move in relation to other materials causes the biggest problems. Materials separate where watertight integrity is needed such as in roof flashing and membranes allowing moisture penetration. A range of solutions exist through the choice of materials, fixing and jointing techniques, size limitations, and reinforcing. In the case of roofs, flexible flashing (natural rubber has more elasticity than synthetics) is used in most areas where material movement may cause leaks (at drains, roof penetrations, and parapet walls).

Since the combination of cold air temperatures and high solar heat absorption by materials cause the greatest thermal stress situations, the most logical solution is to minimize the solar heat absorption at the areas of greatest stress. The building corners, recesses, and roof line are generally the areas of
greatest stress since the solar radiation can be absorbed by one surface and not the other causing the greatest temperature differential (figure 3.95).

![Diagram of typical corner with temperature differentials]

One way to help minimize this stress is to spread the solar heat around the corner gradually with rounded corners (figure 3.96).

![Diagram of rounded corner with temperature transition]

Another way to reduce the thermal stress is through the use of light and dark color shades. The materials near the corners could be a light shade so that less solar heat is absorbed near the corner (figure 3.97).

![Diagram of color shade change and temperature differential]
The strength of materials is also effected by extreme temperatures. In extreme cold temperatures, plastics and synthetic flexible materials can become brittle and subject to cracking should excessive movement occur. Many metals become more brittle in cold temperatures with the shear strength being the most sensitive.  

Deterioration is one of the major problems with concrete. Deterioration is accelerated due to the freeze/thaw cycle (frost action) happening frequently when exposed to solar radiation, cold night air temperatures, and high moisture content (use air entrained conc.).

Timber moves little with temperature, yet, the drying out of the wood can cause cracks or splits which can become especially bad on glulam beams. Low moisture content wood (12%) must be used in order to minimize the cracking and twisting caused when wood dries out during winter.

Selection of the most flexible sealants is essential since they must elongate most when they are least able because of the hardining effect of the cold temperatures.
3.5.4 Precipitation

<table>
<thead>
<tr>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLAR RADIATION</td>
<td>TOPOGRAPHY</td>
</tr>
<tr>
<td>TEMPERATURE</td>
<td>GLACIOLOGY</td>
</tr>
<tr>
<td>PRECIPITATION</td>
<td>SOILS</td>
</tr>
<tr>
<td>WIND</td>
<td>VEGETATION</td>
</tr>
<tr>
<td>SPECIAL CONDITIONS</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PLANNING LEVEL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLANNING LEVEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEVEL 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEVEL 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEVEL 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEVEL 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Several implications with regard to precipitation effect the building fabric make up:

1. The "cold roof" uses the insulating quality of snow while the typical "hot roof" causes problems.
2. The functioning of panels over skylights as well as the skylights themselves can also experience problems with snow melt and ice dams.
3. Care should be taken in the placement of appendages on the exterior since snow and ice may act together to remove them.
4. The exterior building skin must allow moisture to migrate out of the walls as well as keep rain and snow from entering from the outside.

**Cold Roof Versus The Hot Roof**

Snow is most often used as an insulator on roofs where the cool attic space (vented to the outside) keeps the snow from melting. This is known as the "cold roof". To retain this condition during the winter the house interior must be insulated from the attic space which is vented to the outside. The space stays cool enough under the roof so as not to melt the snow cover. The cool attic space becomes a buffer zone for building heat loss, it's temperature on 15°F to 25°F is more temperate than the -20°F to -40°F temperatures outside. In larger buildings, continuous buildings such as row housing, and buildings
with flat roofs proper venting of the attic space becomes more difficult and care should be taken to alleviate the heat and moisture build up under the roof.

A hot roof condition occurs when the inside heat moves the $32^\circ F$ (freezing) isotherm outward into the snow, the snow begins to melt reducing its thickness until the freezing point moves back inside the building. The melted snow runs down until it reaches a cold eave and then freezes creating an ice dam and icicles. The icicles can be hazardous should they fall. The melting snow/ice also will migrate up through roof shingles and into the building interior due to water backing up behind the ice dam (figure 3.99).
Windows In The Roof

How does snow cover normally effect sloping skylights? A skylight insulated with a movable shutter will normally operate until a heavy snow fall moves the $32^\circ F$ isotherm out into the snow, melting that portion adjacent to the roof. When that melted snow freezes back, it will freeze the shutters closed during cold periods. With the help of the interior heat and exterior solar heat, the shutters should be movable from February through November. Should light be desired through these skylight windows during winter, a portion of the shutter or the whole shutter could be glass, much like a storm window (figure 3.100).

When the skylight is left uncovered to the cold winter snow accumulation, the heat loss from the interior going through the glass will melt the snow which accumulates on the glass surface. In this way light can pass through the skylight the whole year at the expense of radiative and conductive heat losses. Watertightness and ice damming become special problems associated with melting snow on a roof/skylight sloping surface (figure 3.101).
• Exterior Appendages

The building itself may have a stack, deck, gutter, or other appendage which could get ripped off when snow slides off the roof. On the eave, ice will grab hold of gutters and facias which are then pulled off with the sliding snow and ice (figure 3.102).

• Moisture Migration Through The Skin

While the exterior walls of buildings serve the purpose of keeping the rain and exterior moisture out of the building, they also must allow for the migration of moisture to the outside which has leaked out from the inside (warmer). One rule of thumb is that the exterior wall surface be 5 times more permeable than the inside wall surface (normally a plastic vapor barrier). Using shiplap siding or shingles are preferred over plywood which allows little moisture migration through its glue joints, requiring holes to be drilled through it in order to allow moisture to escape.
3.5.5 Wind

Wind has a greater heat loss influence on window area than on other areas of the exterior skin. Air movement (wind), along the outer surfaces of buildings, convects heat away from that surface; the insulating air film close to the surface is reduced, increasing the heat loss of the surface. Wind blowing in through cracks around windows, doors, and other openings also increase heat loss. In high wind areas the suction effect on the leeward side of the building can draw air out of the building through the cracks and openings of that side.

When the wind (approximately 15mph) blows against glass windows, the heat loss through the glass can increase nearly 60% with single pane glass and around 12% with double insulating glass. On a normal insulated wall the same wind will increase heat loss about 2% to 3%. Minimizing glass areas exposed to winter winds can be a major factor in keeping building heat loss to a minimum. Covering the window area with exterior shutters as well as breaking up the wind with vegetation or wind poles (figure 3.103) help to varying degrees to reduce heat loss.

<table>
<thead>
<tr>
<th>PLANNING LEVEL 1</th>
<th>PLANNING LEVEL 2</th>
<th>PLANNING LEVEL 3</th>
<th>PLANNING LEVEL 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>REFERENCE MATRIX</td>
<td>CLIMATIC FACTORS</td>
<td>SITE FACTORS</td>
<td>CLIMATIC FACTORS</td>
</tr>
<tr>
<td>SOLAR RADIATION</td>
<td>TEMPERATURE</td>
<td>PRECIPITATION</td>
<td>WIND</td>
</tr>
<tr>
<td>GEOGRAPHY</td>
<td>CLIMATIC FACTORS</td>
<td>SITE FACTORS</td>
<td>SOILS</td>
</tr>
<tr>
<td>TOPOGRAPHY</td>
<td>SOILS</td>
<td>USEFULNESS</td>
<td>PLANNING LEVEL</td>
</tr>
</tbody>
</table>

![Wind poles used to protect house against force of wind](image)
Minimizing cracks around windows, door, and other openings (use of weatherstripping, figure 3.104) as well as orientating fenestration away from the prevailing wind direction helps reduce building heat loss and discomfort close to those openings (figure 3.105).
3.5.6 Special Climatic Conditions

<table>
<thead>
<tr>
<th>REFERENCE MATRIX</th>
<th>CLIMATIC FACTORS</th>
<th>SITE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOLAR RADIATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEMPERATURE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PRECIPITATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WIND</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SPECIAL CONDITIONS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOPOGRAPHY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GEOLOGY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SOILS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BOTANICAL VALUES</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLANNING LEVEL 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLANNING LEVEL 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLANNING LEVEL 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLANNING LEVEL 4</td>
<td></td>
</tr>
</tbody>
</table>

A. Humidity/Moisture Potential

"Water vapor causes problems for everyone - and most of us don't even know it. We know we have problems, all right, but we blame them on some other cause, some other mechanism. For instance, when we get a heavy snowfall in December, and water starts dripping through the ceiling, we diagnose the cause as a leaky roof, and blame the material or the builder. Or when the base of the wall turns dark and damp during a January thaw, and water seeps out to wet the kitchen floor, we suspect bad plumbing. Or when carefully fitted multi-pane windows frost over in October and don't regain transparency until March we sigh, shrug, and conclude that "such is life in the Far North", and that nothing can be done. When the outside walls become diseased with peeling paint, or when the tarred roof blisters and breaks, we are quick to blame the paint, the painter, or the roofer. Always we know these things will happen, and we are confident that we know why.

We are wrong. Often.

In each case, the villain is probably water vapor - or, more properly, the villain is a designer not yet accustomed to design for long, cold winters: his agent is water vapor."

The effects of humidity on building design can be broken down into two categories:

1. Condensation/frost on building interior surfaces which have temperatures below the dew point temperature, and

2. Moisture migration into building materials from interior to exterior (warm to cold)."
**Interior Surface Frost/Condensation**

In most houses the window collects most of the surface condensation since its interior surface temperature is normally much lower than a normal insulated wall. This factor can render a window useless for 4 to 5 months in the North since the exterior cold temperatures can keep the interior glass temperature below dew-point. A second (or even third) window pane can help remedy this problem, only if the moisture laden warm air cannot migrate through to the second window pane where it can condense and freeze on its interior surface which is below dew-point temperature. It becomes essential to seal the inside window pane and not seal the outside pane(s) to allow moisture an escape route (figure 3.106). Factory made double glazing units are normally sealed so this problem should not occur with them.

![Figure 3.106](image)

Moisture/frost can also accumulate on doornobs, masonry, thermal bridges as mentioned before - any cold surface which has access to the interior heated air with higher moisture content. Remedies to this include:

1. Keep interior humidity to a minimum during the cold months (20% or less),

2. Insulate materials so the interior surface temperatures stay above dew-point temperature.

The humidity level in the building interior is regulated by the interior surfaces - the cold surfaces will continually remove excess humidity from the air.
Moisture Migration Into Building Materials

Water vapor which migrates into the walls and ceiling (warm interior to cold exterior) can cause a great deal of material damage as well as reducing the effectiveness of the thermal insulation (impregnated with ice). Steps must be taken to minimize this effect:

1. Provide enough ventilation to keep the relative humidity low on the warm side of the wall/ceiling,
2. Install a "leak-free" vapor barrier on the warm side, and
3. Use highly permeable materials on the cold side or induce ventilation to carry the water vapor out of the building materials.  

Accomplishing step 2 becomes the most difficult in normal housing construction. Some design precautions include:

1. Use large vapor-proof sheets near the warm side of an outer wall or roof insulation.
2. Seal the holes and joints in it.
3. Assure that materials colder than the vapor barrier are able to breathe to the outside air only.
4. Calculate, to make certain that the desired relative humidity is possible, for the design. If it is not, adjust either the design or the humidity.
5. Where walls are of masonry, consider placing insulation on the outside.
6. Consider an "upside down" roof, with the waterproof membrane serving also as the vapor barrier.
7. Avoid any possibilities for multiple vapor barriers (these form vapor traps).

Another precaution in walls is to use 2x2 furring strips over the regular 2x6 wall. Insulate the 2x6 wall space, place the vapor barrier over that, then place the 2x2 strips over the vapor barrier and insulate this space, then apply the interior wall material (figure 3.107). The major reason for doing this type of construction is to avoid vapor leaks through the
vapor barrier most often cut through by the electrical contractor who installs the electrical wiring and fixtures. Ceiling light fixtures should be avoided if they conflict with the vapor barrier in the ceiling.

Step 3, ventilation of the cold side of the building materials, becomes most important in roof construction. In choosing between a pitched roof or a flat roof, the pitched roof should prevail due to the problems of venting a flat roof (natural air flow will vent the sloped roof, figure 3.108). In addition, the flat roof normally used vapor tight coverings which will not permit vapor to escape.
Use of the "upside down" roof (figure 3.109) for flat roofs helps to keep the building mass on the warm side and the insulation on the cold side of the vapor varrier so there should be little or no moisture buildup on the underside of the structure.70
B. Blowing Snow

Infiltration of blowing snow into the building interior through door cracks and windows can be a major problem in the Arctic Zone where the air born snow is constantly working its way in through any cracks or openings (figure 3.110).

Instead of using windows for ventilation, ventilation hoods mounted on the building exterior over ventilating openings are designed to eliminate snow infiltration into the building (figure 3.111). The hood works in principle as a double swirl chamber causing the snow to be dropped before it enters the building interior. The opening of the hood is substantially smaller than the inside space of the hood which will cause the air to accelerate through the entrance and then slow down once inside the hood and lose its carrying capacity.
To reduce the infiltration of snow and ice build-up on door hinges, commercial refrigerator doors which open out were used for the exterior doors on the BP Alaska/Sohio's North Slope Operations Center. As mentioned earlier, orientating openings away from the direct force of the wind as well as the use of arctic entries helps to keep blowing snow from entering the building interior.
C. Permafrost

There are several ways of building on permafrost:

1. Build as you would on normal soils (melting the permafrost),
2. Keep the permafrost frozen.

I will deal primarily with the second step, keeping the permafrost frozen.

The most obvious way to achieve this would be to separate the warm building from the cold ground so no heat can travel from the building to the ground. The best method so far is the elevated structure with at least 2 feet of open air space between the bottom of the structure and the ground (figure 3.112).

This type of foundation (piles, posts, piers) keeps the heat from the structure from reaching the frozen ground, and promotes the unimpeded flow of arctic winds which discourages the formation of snow drifts.

If piles cannot be used for the building foundation, posts and pads can be an alternative (figure 3.113). This type of foundation may experience problems with frost heave which is discussed in the next section.
Other methods for building on permafrost have been tried with less success than the elevated structure. The "floating slab" has been used but is risky even when thick insulation is used beneath it. The reinforced concrete slab (at least 8" thick) is designed to span any minor settlement in the ground (figure 3.114), but if the builder is unfortunate enough to place the slab and house over a sizable ice wedge the whole slab, house and all could end up in an undesirable position (figure 3.115).
D. Frost Heave

There are two actions in the soil which concern designers and builders, adfreezing and frost heave. Adfreezing refers to the strong bond that the winter ground ice grips the foundation with, and frost heave is the upward movement of the soil caused by the ice forming in the soil. Adfreezing is not necessarily undesirable but when it occurs in conjunction with frost heaving it can cause problems such as pile jacking.

Most design responses to frost heave and adfreezing are in the form of prevention which include:

1. Remove frost susceptible material (fine sand and silts) and replace with non-frost susceptible material (course sands and clean gravels).
2. Provide adequate drainage: a drain pipe adjacent to the footing and weep holes in retaining walls (figure 3.116).
3. Place footings below the maximum depth of frost penetration (this can be difficult in the subarctic - Fairbanks' frost penetration is as much as 15 feet yet standard practice allows footings to be set at a 4 foot depth).
4. Provide for movement at the warm/cold interface (figure 3.117).
5. Break the adfreezing bond (on piers and pilings). Should the frost heaving not be prevented, then the house owner must turn to jacking equipment, shims, wedges, and turnbuckles in order to constantly adjust the house to the shifting soil conditions.

![Figure 3.116](image.png)
The use of non-frost susceptible material, good drainage, and the allowance for a certain amount of movement is important when the house has attached "buffer spaces" such as an attached garage, storage room, or greenhouse (figure 3.118).
Breaking the adfreezing bond on pilings is very important if the piling is to stay in the ground since the frost action can remove them completely from the ground. Notching the piling, placing an "anchor" below the active layer, and breaking the adfreezing bond with a sheet of plastic wrapped around the piling all help to keep the piling in place (figure 3.119).
3.5.7 Summary

Listing of building design responses to be considered at planning level 4:

A. Solar Radiation

a. Limit the amount of exposed window area during winter
b. Minimize window heat loss by using movable insulated exterior panels (also, increase window area).
c. Use daytime (buffer or greenhouse) spaces
d. Locate window areas according to needs/desires of inhabitants - view verses light and sunlight, corner windows and daytime spaces are good for view and light/sunlight.
e. Use skylights to:
   1. light the center area of compact building forms,
   2. Bring light to the north end of the house,
   3. Pick up direct sunlight which may be blocked at lower levels.
f. Avoid high heat loss and icing on non vertical window areas.
g. Control direct sunlight and glare with exterior shutters
h. Spring and summer sun can be controlled with the solar reflecting glazing (used best as a movable interior or exterior shading device).
i. Shade the lower portion of windows (up to about 5 feet) from low angle glare.

j. Have light colored roofs (horizontal surfaces).
k. Use dark colors on thermal masses on the south and north orientations.
l. Use light colors on thermal masses facing east, but allow solar heat to penetrate interior for more immediate heat gain.
m. Use panels or shutters over dark colored masses on the west side to control the solar heat input on the thermal masses.
n. Use light colored, textured ceiling and wall surfaces to maximize winter natural light from minimal window area.

B. Temperature

a. Use lightweight insulated construction over heavy thermal mass construction.

b. Use thermal mass "heat bank" earth at basement level by insulating against cold air temperature penetration.

c. Optimize thermal insulation thickness - 5½ or 7½ inches in walls, 9" or more in ceiling/roof, and 2" to 6" in the floor for the Susitna Valley area.

d. Use thermal mass on building interior.

e. Avoid use of single pane windows.

f. Use exterior insulated shutters for windows.

g. Reduce cold air infiltration with fireplace dampers in the stack and a combustion air duct to the exterior.

h. Use of sealed windows best with ventilation handled with separate openings.

i. Use "buffer spaces" for warming incoming air used in air exchanges.

j. Filter and redistribute (reuse) warm interior air.

k. Use of a stack robber on fireplace or heater stacks can put waste heat to use.

l. Avoid creating "cold spaces" - small spaces next to exterior walls closed off to the interior warm air and with no heat source of their own.

m. Avoid creating "cold spaces" between window coverings and windows.

n. Avoid frost formation at building corners.

o. Enclose the building structural system under an insulated exterior skin to avoid thermal bridging.
p. Insulate or provide thermal breaks for metal and masonry (concrete) which extends from the warm interior to the cold exterior.
q. Use of flexible flashing material where high thermal movement occurs and watertight integrity is needed.
r. Use of rounded corners will reduce corner stress due to solar heat build up.
s. Use of light colors at corners will also reduce material stress due to solar heat buildup.
t. Select structural metal which does not lose strength at very low temperatures.
u. Keep freeze/thaw cycles to a minimum on masonry and concrete.
v. Use special dry lumber where strength and no movement is required.
w. Use the most flexible sealants for areas exposed to climatic extremes.

C. Precipitation
a. Use "cold roof" design to utilize insulating qualities of snow and avoid ice dams and related problems.
b. Avoid ice dam build up on cold eaves
c. Provide shutters for sloping skylights (with window area in shutter so light can penetrate when shutter is frozen shut).
d. Avoid exterior appendages which might be removed by snow sliding off the roof.
e. Allow for moisture migration out from the exterior skin, but still keep snow and rain from entering from the outside.

D. Wind
a. Orientate fenestration (doors, windows) away from the winter winds.
b. Use of "wind poles", vegetation, and other buildings to break the wind.
c. Cover outside of the window areas with shutters.
d. Weatherstrip all openings in fenestration.

E. Special Climatic Conditions

1. Humidity/Moisture Potential
   a. Seal inside window panes (vapor barrier) and leave the outside pane loose.
   b. Keep humidity low (+20%) during cold months.
   c. Insulate over (on the outside) cold spots/materials.
   d. Install a "leak-free" vapor barrier on the warm side of the insulation.
   e. Use permeable material on the cold side of the building fabric.
   f. Place insulation on the outside of masonry/concrete walls.
   g. Use the "upside down" roof construction for flat roofs.
   h. Avoid multiple vapor barriers.
   i. Ventilate the cold side of the wall/ceiling insulation where possible.

2. Blowing Snow
   a. Use ventilation hoods to eliminate the snow particles from entering the interior.
   b. Use refrigerator type doors in extreme climatic conditions

3. Permafrost
   a. Avoid building on permafrost
   b. If building on permafrost, keep the permafrost frozen (isolate the building's heat).
   c. Elevate the structure off the frozen ground with pilings or piers.

4. Frost Heave
   a. Avoid building on frost susceptible soils.
   b. Replace frost susceptible soil with non-frost susceptible soil.
c. Provide adequate soil drainage at the base of footings.

d. Place footings below depth of frost penetration.

e. Provide for limited movement at the warm/cold interface.

f. Break the adfreezing bond on pilings and piers with plastic sheets which allow the soil to slide up and down without moving the piling.

g. Use jacking equipment, shims, and wedges for adjusting the foundation to differential ground movement.

h. Anchor pilings in the ground to avoid frost jacking.

Summary of Responses

The primary building consideration at this planning level in both the Arctic and Sub-arctic regions relates to the soil condition since building on unstable soils can negate the best thermally insulated structure built by causing foundation failure followed by structural failure of the building.

Since permafrost in the subarctic region is so close to melting, it becomes very unstable when any change takes place above it - even the clearing of vegetation can melt the permafrost. Therefore, placing a heated building on frozen ground in the subarctic should be avoided if at all possible.

In the arctic region there is no choice, so it is necessary to isolate the warm building from the frozen ground normally by elevating the building.

The frost heaving in bad soils can also cause foundation deformations and failure which again would render the home useless.

The next major consideration involves the combination of moisture migration and temperature, the ability of interior moisture to migrate into the cold building materials. Cold temperatures freeze the
moisture in the materials and ice accumulates for long periods of time due to the duration of cold temperatures. Since the ice normally freezes in the thermal insulation, it reduces the insulating qualities of the material and when the ice begins to melt it stains or rots interior finish materials in the house along with the furnishings. This is why it is extremely important to get an effective vapor seal on the inside of the insulating materials.

Since the house is now on stable ground and the materials can be protected from the migration of moisture and ice accumulation, the next consideration is that of minimizing heat loss. In most cases the fenestration (windows, doors, openings) is the primary concern in heat loss. The use of more window panes, smaller window area, special entries, limited crack space (operable windows and openings to the exterior) and weatherstripping all help to reduce the heat loss attributed to fenestration. Along with the fenestration in importance is the infiltration and air changes. As mentioned above, the use of weatherstripping and minimizing operable windows, and other openings helps reduce the heat loss caused by infiltration and air changes, but the house still needs "fresh air" and oxygen. This can be supplied through "buffer spaces" in which the incoming fresh air can be partially heated from the lost heat of the building interior.

The use of solar radiation is also important in the heat gain/heat loss balance. The optimization of solar heat during much of the year can help to keep the home environment at comfortable temperatures reducing the need for external fuels. The solar radiation can supply very little heat in the winter, so during this period the housing unit should have a heavily insulated exterior skin over its compact shape in order to minimize the heat loss to the constant cold.
References

A. Solar Radiation

1 A building code minimum for most habitable rooms in housing.


3 A Qualitative Checklist for Compact Housing, Greater Vancouver Regional District, Planning Department, Vancouver, 1975, p. 42.


5 The window strip at eye level was used in the Fairbanks' News Miner Addition, Fairbanks; the North Pole Junior Senior High School, North Pole; and the Plumbers/Steamfitters Office Building, Fairbanks.

6 Wider side windows were used in the North Pole High School classrooms for view and light along the wall.

7 Corner window design was used on the south facing corners of the Cook Residence, Fairbanks.

8 "When the House-Warming Sun Goes Down, Movable Insulation Goes into Place", Sunset, Nov. 1976, pp. 166-168.


10 Boris Culjat, Climate and The Built Environment in the North, p. 87.

11 The icicles which form every winter on the greenhouses at the University of Alaska are an extreme example of this.


13 Rice, "Windows", p. 11.

Ralph Erskine, "The Challenge of the High Latitudes".


Victor Olgyay, *Design with Climate*, 1963, p. 34.


B. Temperature


27 Olgyay, *Design with Climate*, p. 119.

28 Ibid., extrapolated from 2" thickness with 1.3 hours time lag.


30 Similar to the Trumbe/Michel solar wall; Steadman, pp. 158, 159.

31 Similar to idea used in GSA's Federal Office Building in Manchester, New Hampshire.


36 Heat loss calculated by author from ASHRAE figures.

37 Used in the Snedden Residence in Fairbanks.


39 Fireplace detail used in the Snedden Residence and the Cook Residence, Fairbanks.

40 Detailing practice in architectural office in Fairbanks.

41 Window detail used in the Bob Sigones House in Fairbanks area.


43 Ibid., p. 32.


46 Rice, "Windows".


50 Detailing practice in architectural office in Fairbanks.

51 Ibid.

52 All nail heads can be seen through the wall covering in the Ellerbe architectural office in Fairbanks.

53 Rice, Arctic Engineering 603, the insulation was being forced off the walls in a shower room due to ice buildup on the cold side of the insulation.

54 In a new tract house in Anchorage, a woman had to be thawed out of her house by a neighbor who came over and used a hair dryer around the door to melt the ice buildup. When they asked the contractor for a remedy, he suggested leaving the door open a bit.


56 Ibid.


58 Typical detailing for roofs in architectural office in Fairbanks.


C. Precipitation


63 M. C. Baker, Ice on Roofs, CBD 89, 1967.

64 Massive ice formations on the eave of the Univ. of Alaska greenhouses in the winter (high humidity inside).

65 The apartment where I lived in Fairbanks had its facia board pulled off on the north side by the ice dam grabbing it and the snow sliding off the roof removing it.

D. Wind


67 Calculated by author from ASHRAE figures.

E. Special Climatic Conditions

1. Humidity/Moisture Potential

61 Rice, "Vapor Barriers".
63 Hutcheon, Humidity and Buildings.
64 Rice, "Vapor Barriers".
65 Ibid.
66 Ibid.

68 Rice, "Vapor Barriers".

2. Blowing Snow

69 Leo Zrudlo, "User Designed Housing for the Inuit of Arctic Quebec", The Northern Engineer, Fall 1974, p. 38.
70 Boris Culjat, Climate and The Built Environment in The North, pp. 292,294.

71 Peter Floyd, "The North Slope Center: How Was It Built?", The Northern Engineer, Fall 1974, p. 31.
3. Permafrost


36 Ibid., p. 13.

4. Frost Heave


38 E. Penner, Ground Freezing and Frost Heaving, CBD 26, Ottawa, 1962.

39 Penner and Burn, Adfreezing and Frost Heaving of Foundations.

40 Penner, Ground Freezing and Frost Heaving.

41 Engineering Detail used in Fairbanks.


43 Ibid., p.18.

44 Ibid.
CHAPTER 4

SITE APPLICATION

4.1 INTRODUCTION

4.2 PHYSICAL FACTORS
   4.2.1 Summary of Climatic Factors
      A. Solar Radiation
      B. Temperature
      C. Precipitation
      D. Wind
   4.2.2 Site Factors
      A. Topography
      B. Geology/Soils
      C. Hydrology
      D. Vegetation

4.3 TOWNSITE LAYOUT
   4.3.1 Analysis of the Townsite Layout
      A. Solar Radiation
      B. Temperature
      C. Precipitation
      D. Wind
      E. Special Climatic Conditions
         Blowing Snow
         Permafrost
         Frost Heave

4.4 CONCLUDING REMARKS

4.5 REFERENCES
4.1 INTRODUCTION

This chapter applies the building design responses from chapter 3 to a specific site situation in the Subarctic North, the Willow Site.

The Willow site lies at the southeast portion of the Susitna Valley in the Alaskan Transitional Climatic Zone. As mentioned in chapter 1, this site has been selected by the people of Alaska for the development of a new city, the Alaska State Capital. For a complete climatic analysis of this area see Appendix A.

The first section in this chapter describes the physical factors of the site (climatic factors and site factors). The second section describes and analyzes a potential site layout for the Willow Site using the design responses from "Planning Level 1" in chapter 3. The specific site conditions establish priorities to the design responses described in chapter 3. The description following the site layout figures tells which design responses took priority in the site layout.
4.2 PHYSICAL FACTORS

4.2.1 Summary of Climatic Factors

The following data is a summary of the climatic conditions at the Willow Site. For more detail climatic information see chapter 2.

A. Solar Radiation
   a. Sun altitude (south) \(41^\circ\) (Dec.) to \(51^\circ\) (June) \(^1\)
   b. Solar azimuth travel \(70^\circ\) (Dec.) to \(290^\circ\) (June) \(^2\)
   c. Hours of daylight 5 hours (Dec.) to 20 hours (June) \(^3\)
   d. % of possible sunshine 45% to 50%/year \(^4\)

B. Temperature
   a. Mean temperatures 10°F (winter), 57°F (summer) \(^5\)
   b. Temperature extremes -40°F to 90°F \(^6\)
   c. Diurnal temperature difference 15°F to 24°F \(^7\)
   d. Heating degree days (65°F base) \(\pm 11,300 \) \(^8\)

C. Precipitation
   a. Average rainfall 10" to 12"/year \(^9\)
   b. Average snowfall 80" (6'8")/year \(^10\)
   c. Maximum snowfall in 24 hours \(\pm 30" (2\frac{1}{2}'") \)^{11}

D. Wind
   a. Winter: Light winds from northerly direction, 3 to 7 mph average velocity \(^12\)
      Maximum wind velocity 40 mph \(^13\)
   b. Summer: Light winds from southerly direction, 3 to 6 mph average velocity \(^14\)

4.2.2 Site Factors

Specific site factors at the Willow Site include:

A. Topography

The Willow Site is located on the gently rising south and southwest slopes of Mt. Bullion in the southwestern foothills of the Talkeetna Mountains. Deception Creek, which traverses the site, separates the meadow uplands from the broad terrace lowlands. The uplands are characterized by undulating topography (figure 4.1). \(^15\)
The elevations within the 100 square mile site range from a low of 300 feet to a high of 3150 feet. The elevation range is from 450 feet to 1500 feet within the development area shown in figure 4.2. The elevation change in the townsite area ranging from 900 feet to 1150 feet.

The slopes above Deception Creek are less than 12% except in ravines. Below the creek slopes are generally not greater than 2% with the exception of isolated hummocky moraines.

The upland areas have a wide choice of potential views:

a. East: The Matanuska Valley (20 miles)
b. Southeast: Knik Glacier (80 miles)
   Chugach Mountains (40 miles)
c. South: Anchorage (35 miles)
   Knik Arm (25 miles)
d. Southwest: Cook Inlet (40 miles)
   Mt. Susitna (35 miles)
e. West: Susitna Valley (10 miles)
   Tordillo Mountains (80 miles)
f. Northwest: Alaska Mountain Range/Mt. McKinley (100 miles).
B. Geology/Soils

The subsurface geology of the Willow Site consists of Glacial Till over 80% of the development area; 10% is at 10 foot depth over bedrock and 10% is sand/gravel/loose rock providing good conditions for spread footing foundations.  

There is no apparent permafrost in the development area of the site.

C. Hydrology

Several isolated small swampy areas are dispersed throughout the area, particularly around the terrain below Deception Creek. The majority of the site is well drained.

The clear water Deception Creek travels through the Willow Site from east to northwest. A creek from the north joins Deception Creek just east of the development area. Several small lakes are located to the west of the development area in the broad terrace lowlands below Deception Creek (figure 4.3).

For domestic water, wells could be drilled or water could be pumped up from the Little Susitna River or Willow Creek. The upper elevations of Mt. Bullion could provide a good place for water storage using gravity flow to service the townsite below.
D. Vegetation

The Willow Site has good birch and spruce forests with stands of spruce and cottonwood near Deception Creek (figure 4.4). Open grassy meadows and relatively sparse forests are found above Deception Creek (figure 4.5).
4.3 TOWNSITE LAYOUT

The following pages contain a potential layout for a townsites within the Willow Site (figures 4.6, 4.7, and 4.8). The town center is situated on the south-facing slope of Mt. Bullion just above Deception Creek with the majority of housing (medium and low density) to the south of the town center on the south side of the Creek. Through the positioning on the slope, the town center has potential views from the northeast around to the south and up to the northwest. The building arrangement within the townsites regulates the general location of buildings by size; the taller more massive buildings are restricted to the north, northeast or northwest sides. Lower, less massive buildings are permitted on the south side closer to Deception Creek. Open areas and park space is located adjacent to the Creek on the south side of the town center.

The higher density housing is located to the north of the town center on the hillside giving many residents maximum exposure to sunlight and views while limiting the shadowing of the buildings to the undeveloped area to the north.

On the south side of the Creek, the medium density housing is located in close proximity to the town center so a maximum number of residents would be able to commute via pedestrian/bicycle routes. The medium density housing is also located here so that its larger building forms do not shadow the lower density housing to the south.

The lower density housing spreads out in a fan shape towards the southeast, south, and southwest. Single family houses, duplexes, and mobile homes are situated along nw/se, north/south, and ne/sw street patterns. The individual housing units are staggered on the site in order to allow winter sunlight to reach the south sides of
most living units as well as the adjacent exterior spaces.

Development outside of the "townsite" area is controlled with certain areas established for dispersed development. In this way many areas adjacent to the townsite can remain natural, recreation areas and not be fenced up by property owners. With the development of the outer dispersed areas, the townsite would have private vehicle parking around the periphery of the town center and transit through the townsite itself would be on a public transport system. This would cut down on the potential pedestrian/automobile conflicts and reduce the production of carbon monoxide and ice fog within the town center.
NORTH-SOUTH CROSS SECTION THROUGH TOWNSITE

40" = 1 MILE (1 mm = 53")

[Diagram]

WINTER SUN

LOW DENSITY HOUSING  MEDIUM DENSITY HOUSING  TOWN CENTER  HIGHER DENSITY HOUSING

DECEPTION CREEK

WINTER WINDS

SOUTH  NORTH

FIGURE 4.8
4.3.1 Analysis of the Townsite Layout

Listed below are the implications of the townsite layout with regard to the climatic factors and site factors:

A. Solar Radiation

The south facing hillside allows the townsite maximum winter, spring, and fall solar radiation (primarily from the south). The central north/south axis of the townsite is located to maximize exposure to the east and west as well as the south (figure 4.9).

The townsite steps up the hillside using the topography to maximize sunlight exposure. The building sizes are arranged with the largest/tallest at the north end of the site (higher density housing) and the smallest to the south end of the site (single family housing), see figures 4.7 and 4.8.

The diagonal street patterns in the town center provide morning and afternoon sunlight corridors, and the main building exposures are to the southeast and southwest (figure 4.6).
The radial street pattern in the housing area to the south of the town center allows winter sunlight to penetrate from the southeast around to the southwest. Housing orientations would range from southeast/northwest, east/west, to southwest/northeast if they were aligned with the street patterns (figure 4.6).

E. Temperature

The whole area is an upland hillside which avoids the settlement of very cold air masses. Cold air will flow to the south and west along the Deception Creek drainage. Keeping the area around Deception Creek in its natural state will help to keep the winter cold air flow from being blocked by buildings.

The compact arrangement of the plan could help to minimize the use of private autos in and out of the town center. A public shuttle could link the lower density housing area to the downtown center.

C. Precipitation

Care should be taken during construction to avoid erosion on the sloping land. Protecting existing vegetation during the initial development will help reduce the erosion potential during the late summer rains.

The street patterns in the steeper portion of the townsite are diagonal to the steep part of the slope minimizing the inclines on which vehicles must climb in the winter snow and ice conditions (figure 4.10).
D. Wind

The townsite should be kept far enough below the brow of the hill (Mt. Bullion) to use both topography and vegetation to help block the winter winds from the north. The townsite should extend no farther than about $\frac{1}{2}$ way up the slope above Deception Creek in order to retain the forested area to the north of the townsite.

The taller buildings on the northeast and northwest side of the town center could slow the cold winds from the north helping to create a more temperate micro-climate in the town center (figure 4.11).

![Diagram of townsite with cold winds and taller buildings]

E. Special Climatic Conditions

- **Blowing Snow**

  Blocking winter winds with the forest cover and buildings to the north side of the townsite would help to minimize any snow drifting in the town center which might occur. Due to the vegetation and lack of sufficient wind, blowing snow and snow drifting is not a major problem.

- **Permafrost**

  The site is free of permafrost permitting standard spread footing foundations with the structures sitting on or in the ground.

- **Frost Heave**

  Most of the site is well drained. The area immediately to the southeast of the housing area appears to have poor drainage and should be avoided if expansion of the housing area occurred.
4.5 CONCLUDING REMARKS

This last part has been an example of the application of the design responses from chapter 3 as they relate to a specific site condition. The intent of this thesis is not to provide a climatic analysis for design at one particular area, the Willow Site, but to describe many differing building responses which could be applied to nearly any specific site condition in the Arctic and Subarctic Regions.

The descriptions of the building design responses at the different planning levels in chapter 3 are the main body of this thesis and the implementation of these is viewed as an ongoing process dependent on the individual needs and specific site conditions.
4.4 REFERENCES

1 Computed from sun path diagrams constructed by the author

2 Ibid.

3 Number of hours of possible sunshine printed in the Anchorage Daily Times, various issues during the year.

4 U.S. Dept. of Commerce, NOAA, Local Climatological Data, Annual Summary with Comparative Data, Talkeetna, 1974 and Anchorage, 1973, National Climatic Center, N. C., extrapolation of data to arrive at figures for Willow.

5 Capital Site Selection Committee, "The Selection of a Capital Site Will Soon Be in Your Hands", supplement to all Alaskan newspapers, summer, 1976.

6 Extrapolation of NOAA data for Talkeetna and Anchorage.

7 Ibid.

8 Ibid.

9 Ibid.

10 Ibid.

11 Ibid.

12 Ibid.

13 Ibid.

14 Ibid.

15 Capital Site Selection Committee.

16 Ibid.

17 Topographic map derived by author from USGS Topographic Map (Anchorage C-8), 1" = 1 mile, 1950 with minor revisions 1971
Capital Site Selection Committee.

Ibid.

Ibid.

Map of hydrological features derived from USGS map, Anchorage C-8.

Capital Site Selection Committee.

Map of vegetation derived from USGS Topographic Map (Anchorage C-8).
BIBLIOGRAPHY

EXPLANATION OF BIBLIOGRAPHY

1. REFERENCE MATERIAL CITED

2. SOURCES CONSULTED
   A. Energy Conservation/Thermal Design
   B. Solar Radiation Studies/Applications
   C. Northern Studies/Building
EXPLANATION OF BIBLIOGRAPHY

The bibliographic material is divided into two major headings:

1. Reference Material Cited, and
2. Sources Consulted.

The first section, reference material cited, is the bibliography of the sources cited at the end of each chapter (end of each section in chapter 3) placed in alphabetical order by the author's last name, or title of work if no author is given.

The second section, sources consulted, is a bibliographic listing of the material consulted which relates to various areas of concern within the thesis. This section is broken into three subsections:

A. Energy Conservation/Thermal Design,
B. Solar Radiation Studies/Applications, and
C. Northern Studies/Building.

The material is placed in alphabetical order by the author's last name or the title of the work if no author is given; the Canadian government publications have 7 subcategories where the publications are listed by publication number from earliest to latest publication date.
1. REFERENCE MATERIAL CITED


CBD 89. Ice on Roofs, 1967.

Housing Note No. 31. Heat Losses From House Basements, 1969.


CBD 146. Control of Snow Drifting About Buildings, 1972.


---

- "Community Design for Production, for Publication, or for the People." *RAIC Journal* (January 1964).


A Qualitative Checklist for Compact Housing. Greater Vancouver Regional District (GVRD), Planning Department, Vancouver, 1975.


... "The Ideal Arctic House - II."

... "Heating The Ideal Arctic House - IIII."
*The Northern Engineer* (Fall 1973): 16-23.

... "Vapor Barriers, The Ideal Arctic House - IV."

... "Windows."


Local Climatological Data, Annual Summary with Comparative Data:


Zrudlo, Leo R. "User Designed Housing for the Inuit of Arctic Quebec." The Northern Engineer (Fall 1975): 36-44.
2. SOURCES CONSULTED

A. Energy Conservation/Thermal Design:


Three Summaries From the National Science Foundation on the Potential Use of Solar Energy For Heating and Cooling Buildings in Varying Locations. Washington D. C.,


B. Solar Radiation Studies/Applications:


C. Northern Studies/Building


1. General:

2. Soils/Foundations:

3. Material Performance:

4. Solar Radiation/Windows:
Reflective Glazing Units, 1968.


Radiation and Other Weather Factors, 1970.


5. Roof Design:

Thermal Considerations in Roof Design, 1965.

Moisture Considerations in Roof Design, 1966.


Drainage From Roofs, 1972.

6. Humidity/Moisture:


Condensation on Inside Window Surfaces, 1960.


Nail Popping: Moisture is the Trouble-Maker, 1962.

Vapor Diffusion and Condensation, 1964.

Moisture Accumulation in Walls Due to Air Leakage, 1966.

7. Air Movement:


Ventilation and Air Quality, 1969.


APPENDIX A

ANALYSIS OF THE CLIMATIC FACTORS IN THE SUSITNA VALLEY AREA

1. INTRODUCTION
2. GEOGRAPHIC AREA
3. SOLAR RADIATION
   A. Sunpath Diagram
   B. Radiation Calculator
   C. Sun Altitude
   D. Sun Asimuth
   E. Number of Daylight Hours
   F. Mean Cloud Cover
   G. Solar Radiation on Building Surfaces
   H. Analysis of Northern Solar Radiation Data
4. TEMPERATURE
5. PRECIPITATION
6. WIND
7. RELATIVE HUMIDITY/MOISTURE POTENTIAL
8. BIOCLIMATIC CHART
9. TIMETABLE OF CLIMATIC NEEDS
1. INTRODUCTION

This is an analysis of solar radiation, temperature, precipitation, wind, and humidity/moisture potential for the Susitna Valley local in the Alaskan Transitional Zone. Explanations are given for the various charts and graphs presented here. Comfort factors are described in the bioclimatic chart and timetable of climatic needs at the end of the appendix.

There are two "sections" dealing with solar heat gain. The first is based on the sunpath diagram and Victor Olgyay's radiation calculator, while the other is based on John Hay's computer programmed radiation values for Whitehorse, Yukon Territory, (61° north latitude). If discrepancies in information exist, John Hay's values would most likely be more accurate.

Much of the information from this analysis is used within the text. Chapter 2, the climatic comparisons, draws heavily from this material.
2. GEOGRAPHIC AREA

The Talkeetna weather station, +350 feet elevation above sea level, is located 80 miles north of Anchorage and 44 miles north of the Willow development area. It lies at the upper end of the broad Susitna River Valley near the junction of the Susitna, Talkeetna, and Chulitna Rivers. To the east the Talkeetna Mountains rise rapidly in a north/south line while the Alaska Range rises some distance to the north with Mt. McKinley appearing to the northwest. The valley area varies between low lying swamp land and slightly higher ground supporting the growth of birch and spruce trees. The river flows south winding its way into Cook Inlet west of Anchorage. The valley orientation being north/south leaves a broad area open to the low winter sun and influences the wind patterns into a north/south profile.
3. SOLAR RADIATION

A. SUNPATH DIAGRAM

The sunpath diagram plots the path of the sun for each month, projecting them onto a flat surface. There are several types of sunpath diagrams, I chose to construct the equidistant type because:

1. It is the most commonly used by designers, being manufactured and distributed by a major glass company, and
2. The solar altitude angles are plotted equally from the outside of the circle (0° altitude) to the center (90° altitude).

This becomes more critical at high latitudes due to the low sun angle much of the time.

Twelve noon is represented by the center north/south line with the hour lines going off to both sides, am (morning) to the east and pm (afternoon) to the west.

From the diagram one can find:

1. Azimuth of the sun at anytime of the day in any month of the year,
2. Solar altitude anytime of the day in any month of the year, and
3. Length of the day during any month.
SUNPATH DIAGRAM
62° NORTH LATITUDE

WINTER SOLSTICE
SUMMER SOLSTICE
B. RADIATION CALCULATOR

The radiation calculator, graphically projected from Victor Olgyay's Total Radiation Calculator, is used in conjunction with the sunpath diagram to determine the possible solar radiation available on any day of the year. By rotation of the calculator on the sunpath diagram, the radiation on a vertical surface can be read for any orientation. The curved lines combine direct and diffuse radiation for a vertical surface while the straight lines projecting out from the center give direct radiation on a horizontal surface and total radiation (direct and diffuse) on a horizontal surface.

The maximum radiation on a vertical surface is available when the sun's altitude is close to 32°, while on a horizontal surface the higher the altitude the more radiation is received. Radiation values are in BTU's per hour per square foot of surface area.
TOTAL RADIATION CALCULATOR

FOR HORIZONTAL SURFACES

FOR VERTICAL SURFACES - NORMAL TO SURFACE

FROM OLGYAY'S DESIGN WITH CLIMATE
C. SUN ALTITUDE

This chart plots the latitude of the sun above the horizon at mid-day for each month. For the Susitna Valley, the smallest angle is about 41° on December 21st and 51° on June 21st. During the equinoxes, September 21st and March 21st, the angle would be 1/2 way between these two angles, 28° altitude.

It has been documented that the biological effect of solar radiation is non-existent below 6° altitude, while the ultra-violet radiation disappears when the altitude is less than 12°. From the first part of November to the first of February the sun remains below the 10° level so that solar heat gain during this time is minimal.

The solar altitude may be calculated by the equation, \( \sin \theta = \cos \phi \cos \delta \cos t + \sin \phi \sin \delta \),

\( \phi = \) solar declination (0° at equinoxes to +23½° to -23½° at solstices),

\( t = \) hours from noon (15° = 1 hour, 0 at noon),

\( \theta = \) latitude (62° in this case).

As an alternative, the sun angle may be scaled graphically off the sunpath diagram with a pivoting sun altitude scale.

D. SUN AZIMUTH

The sun's azimuth is the angle traveled by the sun during the day projected on a horizontal surface. The sunpath diagram is an equidistant projection of the sun's azimuth travel during each month. So on March 21st or September 21st the sun rises in the East, 90° azimuth, and sets in the West, 270° azimuth, with a total travel on 180° in 12 hours. The azimuth is measured from North, 0°. The chart shows the change of azimuths over the year by months.

The higher the latitude, the greater the azimuth change from season to season, the sun travels greater distances in the summer and shorter distances in the winter. At higher latitudes, the longer the summer
days become and the shorter the winter days become till we reach the arctic circle where there is no sun during the winter solstice and 24 hours of sun during the summer solstice (azimuth travel from $0^\circ$ to $360^\circ$).
E. NUMBER OF DAYLIGHT HOURS

This graph plots the estimated actual hours of sunshine per day on a monthly basis. This graph does not distinguish when the sunshine most often occurs during the day (morning, afternoon, evening, or night) as this information is not available.

It can be seen that some months fall above the 50% line, with the peak occurring in late May/early June before the summer solstice, with an average of 10 hours of sunshine in a day 18½ hours long.

F. MEAN CLOUD COVER

The majority of clear days occur in the winter months of December and January during which the days are short, 4½ to 6 hours, and the nights long, 18 to 19½ hours. From April to August the number of clear days are small, from 1 to 6 per month. During this time, the combination of partly cloudy and clear days total less than 50% of the time - most of this time the skies are cloudy.

March and September have the highest percent of sunshine. During these months the length of day and night are close to equal, 12 hours, and the clear and partly cloudy days total 15 to 17 per month.

The horizontal surface gets more radiation than any other surface from mid-April through August, peaking in June. The south facing vertical surface receives the most solar radiation for the remainder of the year.

An east or west vertical surface will get approximately the same amount of radiation during the summer solstice as the south facing vertical surface gets during the equinoxes.
G. SOLAR RADIATION ON BUILDING SURFACES

Using the sunpath diagram for 62° north latitude and the radiation calculator, the amount of total radiation (no cloud cover) was plotted for vertical surfaces facing north, south, east, and west, and for a horizontal surface for each month of the year.

The horizontal surface and the north, east, and west vertical surfaces pick up only diffuse radiation during the winter months making their winter values much lower than those of the south facing vertical surface.

The south facing vertical surface reaches its peak during the equinoxes dropping down in the summer when the sun angle is higher. With the sun angle lower in the mornings and afternoons the maximum radiation for the north, east, and west vertical surfaces occur during the summer solstice, the east surface picking up the majority of radiation in the mornings and the west surface getting its in the afternoons. The north side vertical surface gets summer sun in early mornings and late evenings.
Solar Radiation Max. Possible Per Day on:

- Horizontal Surface
- Vertical Surfaces: South, East/West, North
H. ANALYSIS OF NORTHERN SOLAR RADIATION DATA

Percentage comparison charts were constructed using Dr. John Hay's solar radiation data for Whitehorse, Y.T., approximately 61° north latitude. The data gives solar radiation values for all inclinations (10° intervals) and orientations (45° intervals) for each month of the year. It is assumed that the Susitna Valley will experience more cloud cover than Whitehorse causing less direct solar radiation over the yearly period, especially in the late summer and early fall when the Susitna Valley gets its majority of rainfall.

CHART 1: Direct, Diffuse, and Reflected Radiation

This chart compares these three different sources of solar radiation (%) for each month. The coldest months have the highest percentages for direct radiation while from Feb. through April the direct radiation drops and the reflected radiation becomes high (albedo). The direct radiation averages a little over 52% of the total radiation; the diffuse radiation, 35%; and the reflected radiation, 13%.

CHART 2: % of Yearly Total Radiation

This chart plots the total radiation (direct, diffuse, and reflected) for each month. The coldest months, mid-October through Mid-February, receive only 10% of the total yearly radiation.

CHARTS 3, 4, 5, & 6: % of Direct, Diffuse, and Reflected Radiation on Orientations: North, East, South, West, and Horizontal

These charts compare the direct, diffuse, and reflected solar radiation on the 5 orientations by seasons. Chart 3 plots the winter season (November through February); chart 4 plots the spring season (March through June); chart 5 plots the summer season (July through October); and chart 6 plots the % of total radiation for the whole year to the 5 orientations.
During the winter season, the south orientation receives far more radiation than any other orientation. In the spring and summer the distribution evens out more with the horizontal surface receiving slightly more than the south vertical surface and the south vertical surface receiving slightly more radiation than east or west orientations.

Over the entire year, the solar radiation would have its greatest impact on the south vertical surface (24.8% of the yearly total), with the horizontal close behind (24% of the yearly total). The east and west orientations both receive about 19% of the yearly radiation while the north orientation receives 10% (nearly all diffuse and reflected radiation).
Chart 1
Direct, Diffuse, and Reflected Radiation

61° N. Lat. (Whitehorse, Y.T., Data)

Chart 2

Radiation on Meter
1 sq. meter oriented to north, south, east, west, and horizontal

Ratio of Direct to Diffuse Highest in Winter
Chart 3

Winter Season: Direct, Diffuse & Reflected Radiation

@ 61° N. Lat. (Whitehorse, Y.T., Data)

% of Total Radiation During Cold Months:
- Nov., Dec., Jan., Feb.: 10%

- Orientation:
  - North: Direct, Diffuse, Reflected
  - East: Direct, Diffuse, Reflected
  - South: 6:1 Direct to Diffuse
  - West: 2:1 Direct to Diffuse
  - North: 1:2 Direct to Diffuse

- Coldest Months:
  - November - February

- Total Radiation:
  - South Vertical Surface: 40% of Total Radiation
  - More than twice as much as East or West Orientation

- Nov. - Feb.
  - Nov.: 2%
  - Dec.: 12%
  - Jan.: 2%
  - Feb.: 5%

- Note: Snow-covered surface would be little absorption of radiation.
CHARTS 4 & 5
DIRECT, DIFFUSE, & REFLECTED RADIATION

°61° N. LAT. (WHITEHORSE DATA)

% of Total Rad. (March-June) 20%
% of Total Rad. (July-October) 20%

March, April, May, June
52% of Total Yearly Radiation

July, August, September, October
36% of Total Yearly Radiation
CHART C
TOTAL RADIATION (YEARLY) ON VARIOUS ORIENTATIONS

61° N. LAT. (WHITEHOUSE, YT. DATA)

COMPARISONS

* SOUTH VERTICAL & HORIZONTAL RECEIVE SIMILAR AMOUNTS OF RAD ABOUT 25% OF TOTAL, EACH.

* EAST & WEST GET ABOUT 20% LESS RADIATION THAN SOUTH & HORIZ.

* NORTH GETS 50% LESS RAD. THAN EAST OR WEST

ORIENTATION

JANUARY — DECEMBER
4. TEMPERATURE

The winter period, during which the ponds, lakes, and rivers are frozen, falls between mid-October to mid-April. Periods of clear, cold weather alternate with cloudy, mild weather during the winter. First snow will occur around late September and will stay on the ground from mid-October till April with an occasional "January Thaw" which reduces the snow level accumulation.

The Alaska Range is an effective barrier between the very cold air in the interior and the warmer air in the Cook Inlet area. The extreme cold winter weather, associated with a high pressure system over Interior Alaska, may lead to a succession of clear days with temperatures dropping to \(-20^\circ\) to \(-35^\circ\)F (extremes to \(-40^\circ\)F do not occur every year).

During December and January, because of the low sun angle, the diurnal effect on temperature is minimal. The major effect on temperature is cloud cover, when the skies clear, the temperature drops rapidly in the low lying areas when there is little wind. These are the cold temperature inversions which account for most of the extremely cold temperatures. The coldest temperatures are normally in the lowest valley areas since the cold air flows down to these areas (katabatic wind). On hillsides several hundred feet up, the temperatures may be as much as \(25^\circ\) to \(30^\circ\)F warmer than the lower areas.

Looking at the graphs, great temperature changes occur rapidly in April and May, warming up, and in September and October, cooling off. The summer temperature average high in July is less than \(68^\circ\)F. Extremes may reach \(90^\circ\)F on a rare day with a maximum extreme of \(80^\circ\)F more often.

The duration of the winter is an important design factor. The average daily temperature is \(32^\circ\)F (freezing) or below for seven months of the year. For the remaining 5 months the average temperature is slightly more than \(50^\circ\)F, with the highest monthly average of \(58^\circ\)F.
5. PRECIPITATION

Average annual precipitation is approximately 28", nearly twice that of Anchorage to the south and more than twice that of Fairbanks in the interior. The average annual snowfall of 100" (8'4") falls with nearly even distribution from November to March with less than 20" per month. The extremes drop 30" to 40" per month every few years while 50" to 70" have been recorded (maximum over 40 year period). Maximum yearly ranges from 202" to a minimum of 31" over the 40 year period. In the extreme case over 24 hours, three feet of snow has fallen.

With the absence of strong persistent winter winds, with the exception of an occasional gusty period, it is assumed that blowing snow is not a major problem in the area. While snow may drift some during windy periods, the problem is not such a critical design consideration as it is in the northern coastal areas such as Barrow and Kotzebue.

Summer storms and cloudiness from late July through September have a cooling effect on the daytime temperatures during this period, allowing less solar radiation through the cloud cover.
### Total Precipitation and Snow

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precip.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Unit: Inches of precipitation and snow.
6. WIND

Due to the north/south orientation of the lower Susitna Valley, the winds blow from either the north, northeast, or from the south, and southwest. September through April, the colder months, the wind is predominately from the north, northwest with the higher wind speeds coming from the northeast. May through August the wind is predominately from the south with the higher wind speeds coming from southeast to southwest.

Average monthly speeds range from 3 to 6 mph in the winter and 3 to 4 mph in the summer. The wind speed of 38 mph was a maximum recorded over a 7 year period. Over the same period to the south, Anchorage experienced winds over 60 mph. Wind velocity averages for the Talkeetna area are relatively low decreasing chances of driving rain and blowing snow.
The air's capacity for water vapor increases with an increase in air temperature as shown on the Moisture Potential Capacity of Air graph. The potential shown for vapor pressure, absolute humidity, and specific humidity would be under 100% relative humidity conditions. Taking only the vapor pressure, we can see that in January (mean temperature 9°F) we get a range from 1.09 to 1.23 mmhg vapor pressure (62% to 70% relative humidity). In July (mean temperature 58°F) we get a range of 7.5 to 11.13 mmhg vapor pressure (60% to 89% relative humidity). There is 7 to 9 times the vapor pressure in July than in January even though the relative humidity does not differ that much.

The major problem concerning humidity is the low moisture potential in the air at cold temperatures. When brought into a warm environment (building interior), the relative humidity value drops very low. To remedy this people increase the humidity within the home which then migrates out towards the cold exterior causing potential damage.

During the summer months, relative humidity over a 24 hour period may range from 50% to 90%. The cool summer temperatures keep the potential for a hot humid day very low, see the bioclimatic chart.
MOISTURE POTENTIAL CAPACITY OF AIR VS AIR TEMP.

1. THE COLDER THE TEMP., THE LESS POTENTIAL MOISTURE.

Ex. 60% REL. HUMIDITY

A. MOISTURE IN AIR @ 30°C (86°F) = 19 mm Hg. VAPOR PRESSURE
   18.4 g/m³ ABSOLUTE HUMIDITY
   15% g/l. SPECIFIC HUMIDITY

B. MOISTURE IN AIR @ -20°C (-4°F)
   Vp mm Hg. VAPOR PRESSURE
   15.9 g/m³ ABSOLUTE HUMIDITY
   15% g/l. SPECIFIC HUMIDITY

30 TIMES MORE VAPOR PRESSURE
17% TIMES MORE ABSOLUTE HUMIDITY
39% TIMES MORE SPECIFIC HUMIDITY

TALKING TO:

AVG. JAN. TEMP @ 60°F

RELATIVE HUMIDITY RANGE 70% 123 mm Hg. VAPOR PRESSURE
AVG. JUL. TEMP @ 90°F

RELATIVE HUMIDITY RANGE 80% 19.0 mm Hg. VAPOR PRESSURE

DATA FROM TABLE III
P. 13 GRIERSON
MAN. CLIMATE & ARCHITECTURE
3. BIOCLIMATIC CHART

This chart plots the temperature and humidity together. The human comfort zone is shown with regard to solar radiation (BTU/hr.), relative humidity (%), and temperature (°F).

Even during the summer months we need the presence of solar radiation to attain the desired degree of comfort. Occasionally an extreme maximum temperature may put us above the comfort zone; these happen so rarely that they would be welcomed extremes.

Between mid-September and mid-May, even if it were possible to get over 300 BTU/hr/sq.ft., we would still be below the physical comfort zone. Optimizing for the climatic elements, solar radiation, etc., the physical requirements cannot be met without the introduction of mechanical heating systems.

Clothing and activity are also to be considered when describing the comfort range.
9. TIMETABLE OF CLIMATIC NEEDS

In most areas in the "lower 48" this chart would tell what time of year and time of day that shading and cooling breezes are necessary as well as solar heat and wind protection. There is no overheated period so the area needs solar heat 100% of the time although during some summer days 100% of the sun's radiation would cause overheating, considering the sun rises close to 3am and sets around 9pm giving over 18 hours of possible sunshine to exposures from northeast, east, south, west, to northwest.

The sunrise and sunset lines show the rapid increase and decline of daylight over the year. Increases and decreases occur at the rate of 6 to 8 minutes a day.
APPENDIX B

BUILDING SPACING AND TOPOGRAPHY
The topography can be used to increase the availability of winter sunlight by building on south facing hillsides. Charts B.1 through B.4 plot the spacing required between buildings at different latitudes for similar sunlight penetration for flat topography, 5° slope, 10° slope, and 22½° slope.
**Plan View of Building Spacing**

**Distance (H):**
Building spacing required for sun penetration on Dec. 21st, 5' above grade (127' shown for 1-story building, 62° N. Lat.)

70% more powerful sun

378% higher altitude at midday
DISTANCE \( h \) DERIVED FROM: \[ h = \frac{\alpha}{\tan A}, \quad \alpha = (15'-5'), (25'-5'), (35'-5'), (45'-5') \]
\[ A = 4.5^\circ \]
\[ h = 127', 250', 375', 500' \]

BUILDING SPACING REQUIRED AT 42° N. LAT. ON DEC 21ST

TO ALLOW SUNLIGHT PENETRATION 5' ABOVE GRADE

FOR 1 STORY (15'), 2 STORY (25'), AND 3 STORY (35') BUILDINGS
BUILDING SPACING (SOUTH) FOR SUN PENETRATION ON DEC. 21
5' ABOVE GRADE
FLAT TOPOGRAPHY

GEORGIAN LATITUDE
858' BUILDING SPACING TO SOUTH TO ALLOW SUN TO PENETRATE EACH BLDG.
5' ABOVE GRADE ON DEC. 21

DISTANCE REQUIRED BETWEEN BUILDINGS (FEET)

LATITUDE CHANGE

CHART B.1
Building spacing (south) required for sun penetration on Dec. 21st, 5' above grade

5° slope

Chart: Building spacing chart for sun penetration.
BUILDING SPACING (SOUTH)
REQUIRED FOR SUN PENETRATION
ON DEC. 21st, 5' ABOVE GRADE

10° SLOPE

DISTANCE REQUIRED BETWEEN BUILDINGS (FEET)

LATITUDE CHANGE

CHART B.3
BUILDING SPACING (SOUTH)
REQUIRED FOR SUN PENETRATION
ON DEC. 21ST, 5° ABOVE GRADE

22 1/2' SUPE (25% GRADE)

LATITUDE DIFFERENCE

CHART 2-4