To all Architects and Developers, please consider the environment and occupants of your project
ACKNOWLEDGEMENTS

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<td>The American Society of Heating, Refrigerating, and Air Conditioning Engineers</td>
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<td>BAuA</td>
<td>Bundesanstalt für Arbeitsschutz und Arbeitsmedizin. Translation: Federal Institute for Occupational Safety and Health</td>
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<tr>
<td>BLS</td>
<td>Bureau of Labor Statistics</td>
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<tr>
<td>CBE</td>
<td>Center for the Built Environment</td>
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<tr>
<td>CFM</td>
<td>cubic feet per minute</td>
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<td>IEQ</td>
<td>Indoor Environmental Quality</td>
</tr>
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<td>IFA</td>
<td>Institute for Occupational Safety and Health of the German Social Accident Insurance</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, Ventilating, and Air Conditioning</td>
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<td>KILM</td>
<td>Key Indicators of the Labour Market</td>
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<td>LED</td>
<td>Light-emitting diode</td>
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<tr>
<td>LEED</td>
<td>Leadership in Energy &amp; Environmental Design</td>
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<tr>
<td>lx</td>
<td>Lux (SI unit of luminance)</td>
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<td>MSDs</td>
<td>Work-related musculoskeletal disorders</td>
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<td>Nord/LB</td>
<td>Norddeutsche Landesbank</td>
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<td>OES</td>
<td>Office Environmental Survey</td>
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<td>OSHA</td>
<td>Occupational Safety &amp; Health Administration</td>
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<td>OSHSPA</td>
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<td>RWE</td>
<td>Rheinisch-Westfälisches Elektrizitätswerk</td>
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<td>SBS</td>
<td>Sick Building Syndrome</td>
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<td>STC</td>
<td>Sound Transmission Class</td>
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<td>UN</td>
<td>United Nations</td>
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According to a March 2005 Microsoft survey, Americans work an average of 45 hours per week; sixteen of those hours are labeled “unproductive.” As the average working time in countries like America and Luxembourg has steadily increased over the decades, so too has the knowledge in understanding how office environments affect productivity. Several studies prove productivity is affected by several factors including: access to natural day lighting, office furniture, office organization, temperature, indoor air quality and ventilation, ergonomics, and acoustics. Poor workplace design can cost U.S. businesses at least $330 billion in lost productivity per year. Considering more money is typically spent on salaries rather than building costs, companies could realize significant savings by providing properly designed office buildings. Companies can further save on long term energy costs if their office buildings are designed sustainably. Recent “green” projects such as Commerzbank by Norman Foster have addressed these issues so employees can work more productively in their environments.
This thesis will concentrate on three renowned sustainable high rises in Germany and will evaluate the elements needed to enhance productivity. Data for the selected buildings will be collected through surveys, personal observations, and interviews to provide feedback on the pros and cons of the buildings’ sustainable features directly affecting their workspaces. The survey asks employees to rate different factors affecting productivity, such as light, temperature, and acoustics. This research provides a better understanding if the selected buildings have the elements needed for office productivity. Recommendations for a typical office to enhance productivity are also explored.
CHAPTER 1
INTRODUCTION

The most popular definition of sustainability can be traced to a 1987 UN conference. It defined sustainable developments as those that "meet present needs without compromising the ability of future generations to meet their needs." In other words, we should minimize consuming both Earth’s non-renewable and renewable resources so future generations may benefit from the same. Humans use many resources for energy and to create materials. As a result, carbon dioxide and other by-products, such as toxic gases, are released into the environment. The excessive carbon dioxide released into the atmosphere creates what the earth experienced as “global warming” (Woodwell 5). Buildings are the biggest consumer of energy, accounting for consumption of 48% of all energy in America, while the rest is consumed by Transportation (27%) and Industry (25%) (US Energy Information Administration). Therefore, buildings should invest in low-carbon technologies and ultimately be designed sustainably.
Figure 1-1. A) Average global temperature increases as carbon dioxide concentrations increase. (Source: Woodwell). B) US Energy Consumption pie chart. (Source: US Energy Information Administration).

From an architectural standpoint, sustainable design is about making responsible decisions to maximize passive design strategies for heat loads, and to minimize the use of both renewable and non-renewable resources for the building’s construction and life cycle. This could range from using green roofs, efficient insulation, rainwater collection, using renewable energy (solar, wind, geothermal), and recycling materials. Climate
should be the first factor of consideration when designing a building. Buildings
designed in hot climates will use different passive cooling strategies than buildings
designed in cold climates. Overhangs, for example, should be sized so enough direct
sunlight enters a window during winter, but provides shade during the summer for
places with moderate climates. Equally as important, is to provide a healthy
environment to meet the needs of the occupants with elements such as access to
natural day lighting and operable windows to provide fresh air, using non-toxic materials
on surfaces, and providing ergonomic equipment. When office workers are satisfied
with their environmental conditions, with greater comfort and control, they will be more
productive (Lomonaco and Miller 2). The line between energy and occupants’ needs
must meet at some point in order to foster good design. Architects are responsible for
creating the tools, places, processes and systems which optimize human well-being.
CHAPTER 2
WORK AND OFFICE PRODUCTIVITY

Employed Americans work an average of 7.6 hours on the days they worked with 86 percent of them doing some or all of their work at their workplace (Bureau of Labor Statistics 2008). For those working in office buildings, the building will become a part of their lifestyle. The percentage of people who work in office buildings will continue to rise as the world’s population moves into urban cities, especially in developed countries. The United Nations Population Division estimates the current world urban population is at 50.6 percent and by 2050 it is expected to be at 69.6 percent (United Nations 75). This could suggest that as the world becomes more urban, less space will be available for construction and therefore high density construction will appear more due to its efficiency.

It is possible, in the future; people will also work even longer hours. Americans, in fact, work more hours per year than workers in most other developed economies. According to Key Indicators of the Labour Market (KILM), Luxembourg and the United States had the largest shares of persons working at least 40 hours (78.8 and 76.6 percent, respectively). The KILM study also suggests work hours will continue to rise in certain parts of the world, such as in Latin America. For those working long hours, the office environment in which they work will influence their lifestyle. Working long hours, however, doesn’t exactly mean one is more productive. “The more hours you work, the less satisfied you become with your life, even though you make more money” (McKibben 114). This could be why, measured as value added per hour worked, Norway has the highest labor productivity level (US$ 37.99), followed by the United States (US$ 35.63) and France (US$ 35.08) (KILM). Additionally, “The more hours you
work, the bigger you ecological footprint, too. That’s because you’re spending more money and spending it carelessly; with no time to go to the farmer’s market, let alone cook what you buy there, you drive through the drive through instead” (McKibben 115). “In 1930, in the teeth of the Great Depression, the cereal entrepreneur W. K. Kellogg put his workers on a six hour day at full pay. Productivity increased dramatically, helping pay for all the experiment” (115). If buildings were designed in a way to make people happy and productive, fewer hours would be spent working. From this, better office design equals should better work performance.

For companies constructing buildings for their employees, finding the balance between using the least amount of energy and productive work environment is essential. Architects alike should consider this environmental aspect as it directly affects inhabitants. Productivity, for example, is directly related to work environments. A 2008 Gensler survey estimates companies would be able to perform an average of 22% more work if their companies had better designed physical working environments (Gensler 2008). “An employee's workplace is responsible for 24 percent of their job satisfaction level and this can affect staff performance by five percent for individuals and 11 percent for teams” (Management-Issues).

The greatest expense companies have is employee salaries. If the average construction cost of a building is $20 per square foot when amortized over 25 years, there is an average of $200 per square foot spent on salaries per year, while energy costs are roughly $2 per square foot per year (Callan). “As little as a 1 percent increase in productivity would be the equivalent of $2 per square foot per year cost savings, covering the annual energy bills. A 10 percent increase in productivity would be
equivalent to $20 per square foot per year cost savings, which would pay for the building itself” (Callan). According to an analysis conducted by the research firm D/R Added Value, poor workplace design costs U.S. businesses at least $330 billion in lost productivity per year (Gensler 2006). Companies could lose money from employees using sick time due to building related illnesses or even from distractions such as when an uncomfortable temperature results in employees frequently adjusting the temperature of their office. Nine in ten workers believe better office design leads to better overall employee performance (Gensler 2008). By investing in productive office design, a company could save on salaries.

By contrast, poor workplace design is linked to lower business performance and higher stress levels experienced by employees (Management-Issues). Unfortunately, many businesses seem to ascribe a low value to workplace design. Forty-six percent of workers do not believe creating a productive workplace is a priority at their companies, and 40% say minimizing costs is the main reason behind their workplace’s current layout. One in five respondents rated their current physical workplace environment as being only ‘fair to poor’ (Gensler 2006).

According to the Gensler survey, “Over one third of respondents say their current workplace design does not promote health and well-being; yet healthy and secure working conditions are reported as the most important factors in an efficient working environment.” Increased productivity is mainly the result of a firm better combining capital, labor and technology. A lack of investment in people (training and skills) as well as equipment and technology can lead to an underutilization of the labor potential in the world (ILO News). The graph below, for example, demonstrates that occupants who
can control their surrounding (temperature, ventilation, and lighting), rather than using an automatically controlled building, will be more productive.

![Figure 2-1. Productivity versus degree of control. The Office Environmental Survey (OES) revealed fewer building-related illness symptoms and greater productivity as the perceived level of individual control increases. (Source: Bordass, B. 2).](image)

In order to build a place for productivity, the direct environment must be studied. There are many instances in buildings where the temperature extremes become too distracting or air quality causes sicknesses. Buildings must have the design and tools so positive outcomes of health and productivity can be integrated into the initial cost-benefit calculations and then energy and maintenance costs. In the following chapter, a closer look into these factors affecting the work environment will be discussed. The factors listed are: air quality, thermal comfort, light, acoustics, green views, ergonomic control, and office layout.
CHAPTER 3
FACTORS AFFECTING PRODUCTIVITY

Air Quality

"Air-conditioning systems tend to have two settings: too hot and too cold: give me an openable window anytime." Barbara Ritchie, Inland Revenue, E Kilbride

Millions of Americans work in buildings with mechanical heating, ventilation, and air-conditioning (HVAC) systems; these systems are designed to provide air at comfortable temperature and humidity levels, free of harmful concentrations of air pollutants. Ventilation is a combination of processes which results in the supply and removal of air from inside a building. These processes typically include bringing in outdoor air, conditioning and mixing the outdoor air with some portion of indoor air, distributing this mixed air throughout the building, and exhausting some portion of the indoor air outside. The quality of indoor air may deteriorate when one or more of these processes are inadequate. For example, exhaled carbon dioxide may accumulate in building spaces if sufficient amounts of outdoor air are not brought into and distributed throughout the building. Carbon dioxide is a surrogate for indoor pollutants that may cause occupants to grow drowsy, get headaches, or function at lower activity levels (USEPA 1991).

Carbon dioxide and other pollutants like mold in the air may have developed what was termed as “Sick Building Syndrome” in the 1970s. Sick Building Syndrome (SBS) started in the late 70s, after the 1973 oil embargo, when buildings were limited to 5 cfm of fresh air per occupant from mechanical air conditioning to save money on high fuel prices. Many buildings built then suffered from air quality problems related to
dampness, including mold and other microbial growth. The causes of SBS are from chemical and biological pollutants such as:

- Mold, mildew, and other moisture-related contaminants
- Off-gassing from building materials and furnishings
- Chemical and maintenance products, including pesticides
- Combustion gases from appliances, automobiles, and tobacco
- Naturally occurring gases such as radon
- Outdoor pollutants that enter the building (American Institute of Architects 309)

Symptoms of Sick Building Syndrome include headache, eye, nose, or throat irritation, dry cough, dry or itchy skin, dizziness, nausea, difficulty in concentrating, fatigue, and sensitivity to odors (USEPA 1991).

Therefore, air quality is directly related to health. A fresh supply of outdoor air can dilute the amount of airborne contaminants in building. Fresh air finally became an important issue in the late 80’s. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) recommends the standard fresh air requirement for an office building should be 20 cfm/person based on their "Standard 62-2007: Ventilation for Acceptable Indoor Air Quality." This standard explains "minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects." Standard 62-2007 is a voluntary standard, which means it becomes enforceable only after a state or locality adopts the standard in its building code. Furthermore, most current building codes pertaining to ventilation are standards only for the way buildings in a particular jurisdiction must be designed; they are not enforceable standards for the way the buildings are operated (Ventilation and Air Quality in Offices). Currently only 26 states and territories approve OSHA's state plans from the Occupational Safety and Health State Plan Association (OSHSPA).
It is generally agreed that poor indoor air can adversely affect employee health and productivity. A study by Milton found the absence rate, controlling for age, gender, seniority, crowding, and type of workspace was 35% lower in the high-ventilation buildings (Milton). A Report to Congress on Indoor Air Quality states economic costs to industry from indoor air pollution have been estimated to be in the “tens of billions of dollars per year” (USEPA 1989). Reducing Sick Building Syndrome symptoms by 20-50% at work for ~15 million workers could save $10-$30 billion in savings or productivity gain (Fisk). In an article by Seppanen, Fisk, Faulkner, they found “with a simple example using night-time ventilative cooling, energy efficient methods are available to improve the indoor environment. For this example, the ratio of productivity gains to energy used by fans varied from 32 to 120 depending on cost of the electricity (Seppanen, Fisk, Faulkner 7). Improvements in the indoor air environment may substantially increase employee morale and productivity. Therefore, it is important to include indoor air quality controls in operation, maintenance, and energy conservation strategies.

**Thermal Comfort**

Thermal comfort is directly affected by temperature and humidity. The perception of thermal comfort is also influenced by radiant temperature, air velocity, occupant activity, metabolism, gender, and clothing insulation. Therefore, thermal comfort varies among individuals. “The indoor temperature affects several human responses, including thermal comfort, perceived air quality, sick building syndrome symptoms and performance at work” (Olli Seppänen, William J Fisk, QH Lei 2). ASHREA Standard 55-2004 provides guidelines intended to achieve thermal conditions 80 percent of the occupants would to find acceptable or comfortable. They recommend that during
summer, if relative humidity is 30 percent and the person is wearing light clothing, then the temperature should be 76-82°F. If the humidity is 60 percent, then the temperature should be 74-78°F. For a person wearing warm clothing during winter, the temperature should be between 69-78°F if the relative humidity is 30%. A general recommendation for an office is that the temperature be held constant in the range of 21-23°C (69-73°F) (Canadian Center).

Relative humidity levels below 25% are associated with increased discomfort and drying of the mucous membranes and skin, which can lead to chapping and irritation. Low relative humidity also increases static electricity. High humidity levels can result in condensation within the building structure causing potential for mold and fungi. Generally it is normal for large buildings to supply humidity during the winter and to remove it during the summer (Health Canada 22).

A study found there was a decrease in performance by 2% per °C increase of the temperature in the range of 25-32°C (77-89°F), and no effect on performance in temperature range of 21-25°C (70-77°F) (Seppänen 2) in his experiment of the linkage between productivity and temperature. The study also stated “high temperatures, in practice, may be associated with low ventilation rate.” However, “the ventilation was constant, thus the results indicate only the effect of temperature. Low ventilation combined with high temperature would most probably decrease the productivity further due to the increased prevalence of SBS symptoms and other effects” (9). Another study found low temperatures have been found to decrease dexterity of hands with indoor temperatures between 20-22°C (Messe).
Given the optimum temperature depends on the nature of the task, and varies among individuals and over time, some researchers have advocated the provision of individual control of temperature as a practical method to increase productivity. A study in an insurance office, using the number of files processed per week as a measure of productivity, suggested that the provision of individual temperature control increased productivity by approximately 2% (Kroner and Stark-Martin). Another study by has estimated that by providing workers ±3°C of individual control, there should be about a 3% increase in performance for both logical thinking and very skilled manual work, and approximately a 7% increase in performance for typing relative to performance in a building maintained at the population-average neutral temperature (Wyon).

**Light**

Lighting is believed to potentially influence human performance “because work performance depends on vision, and indirectly because lighting may direct attention, or influence arousal or motivation. Several characteristics of lighting, e.g. illuminance (the intensity of light impinged on a surface), amount of glare, and the spectrum of light, may theoretically affect work performance (Spengler J.D., Samet, J.M., & McCarthy, J.F. 4.22). “Physiologically, daylight is an effective stimulant to the human visual system and the human circadian system. Daylight reduces the incidence of health problems caused by the rapid fluctuations in light output typical of electric lighting with discharge lamps” (Çakir 7). Conversely, lighting extremes can also adversely influence performance (Fisk).

Both natural and artificial light have important roles in an office environment. It is preferable to maximize the amount of daylight in an office for many reasons. One
reason is natural daylight reduces the need to use energy for artificial lighting during the day. Another reason may be because of its high color rendering. The Whole Building Design Guide website states “Electric lighting accounts for 35 to 50 percent of the total electrical energy consumption in commercial buildings” (Ander) with the addition of supplemental mechanical cooling needed for the heat generated by lights. “The energy savings from reduced electric lighting through the use of daylighting strategies can directly reduce building cooling energy usage an additional 10 to 20 percent. Consequently, for many institutional and commercial buildings, total energy costs can be reduced by as much as one third through the optimal integration of daylighting strategies” (Ander).

Humans instinctively prefer to see natural daylight as it stimulates a productive environment. In fact, “studies have shown ample daylight and proper ventilation lead to greater satisfaction, and increased sense of comfort, fewer sick days, and increased productivity” (AIA 309). In addition, “Natural light and views to the outdoors can help enhance physical and mental health. Ample daylight increases productivity in the workplace and test scores in schools” (309)

Thus, it should be no surprise that in Germany, all work places intended for permanent use must have visual contact with the outside world. This is to ensure an employee relaxes their eyes from the computer screen. The Deutsche Industrie Normen gives guidelines and regulations for office design. In practice, “every workplace is located within 6 m of a window” (Meel 89) to afford adequate daylighting to each worker. This requirement explains why German floor plans are so narrow. Additionally, the German legislation EN 12464-1 requires a minimum of 500 lx in a workplace.
However, this is only for artificial lighting because natural daylighting is not defined under these terms. The Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) states:

Today, the state-of-the-art of science and technology is that illuminances for office and VDT-workplaces of 500 lx and of 1,000 lx for those in open plan offices are to be planned. If these illuminance values are maintained - even with partly or fully missing daylight - and the rest of the quality criteria for artificial lighting considered, accidents as well as undue stress and strain and fatigue for the workers will be avoided.

This further stresses the importance of having a minimum standard to ensure adequate lighting levels.

Daylight and views can be maximized several ways. One is by coupling a narrow building section with careful window placement. A general rule-of-thumb is, for a vertical window, useful daylight penetration is up to a depth equal to 2.5 times the height of the effective window head above the horizontal surface of interest. Desired amounts of daylight also can be achieved with the use of skylights, atriums, and light shelves, the shape of the windows and ceilings, and use of light-colored surfaces. Natural daylight also presents the challenge of heat and glare. Care must be given to avoid excessive heat gain from direct solar rays and minimize glare (AIA 309). This could be achieved with the use of satin finishes, translucent curtains, and an automated or manual system.
of exterior blinds. Some office buildings have even used a smart system which moves shading devices according to the actual daylight readings from sensors. The individual controllability of daylight will give even more satisfaction to an office worker and an individual task lamp may help this even more.

The types of light fixtures must also be considered as certain lighting may lead to better occupant satisfaction. Although incandescent light bulbs are great for illuminating a room, they are not energy efficient. Fluorescent light fixtures, conversely, use 75 percent less energy than an incandescent bulb (Energy Star) but, according to Helen L. Irlen, could create negative effects such as triggering headaches, migraines, and eye strain (Irlen). LED lights and full spectrum fluorescent light, on the other hand, have proven to be a great alternative for both energy savings and quality of light. "The study by the Commission for Architecture & the Built Environment and the British Council for Offices has found even simple things such as good lighting and having adequate daylight can reduce absenteeism by 15 percent and increase productivity by between 2.8 percent and 20 percent" (Management-Issues). In another study by Hedge, occupants reported both lensed-indirect and parabolic downlighting supported reading and writing on paper and on the computer screen better than a recessed lighting system with translucent prismatic diffusers (Hedge). A laboratory study by Veitch & Newsham found the type of luminaire influenced performance of computer based work (Veitch). Also, energy-efficient electronic ballasts, which result in less lighting flicker than magnetic ballasts, were associated with improvements in verbal-intellectual task performance" (Fisk).
Acoustics

Acoustics is an important factor affecting productivity. Noise has been recognized as one of the main problems in open-plan office. A Danish study concludes that office noise and type of office environment have a significant effect on office tasks that included processing words. “Compared to a cellular office, the open-plan offices caused significantly higher dissatisfaction with noise in the environment and decreased subjects’ ability to concentrate” (Balazova 7). The Federal Institute for Occupational Safety and Health (BAuA) of Germany recommends an office have a noise level no higher than 55 dB (A), about the same level as a normal conversation. Lower levels between 35 and 45 dB (A) should be designed where higher levels of concentration are required, for example when working on the computer (BAuA 17). To reach these levels, BAuA recommends using quieter electronic data processing equipment (17). State of the art computers and printers produce noise levels of maximum of 48 dB (A). Offices could also be designed with sound absorption materials or sound isolating assemblies.

Green View

As the world population moves towards cities (UN), people could be finding less time in parks and nature. This trend could be the cause of health related issues, even if minor (Univ. of Illinois). As humans, it is in our biological nature to want to be in nature. Several studies have been conducted revealing humans naturally desire views of trees, plants, and landscapes. Frances Kuo, a professor of natural resources and environmental science and psychology at the University of Illinois, said “nature is essential to the physical, psychological and social well-being of the human animal” (Univ. of Illinois). The presence of plants can also promote feelings of well-being and mental equilibrium at home, the office, or places where people will spend many hours.
Plants have also been found to improve spirit, health, and efficiency in studies conducted in the Netherlands, Norway, the USA and in Germany (BAuA 34). One study commissioned by the Bavarian State Institute for Viticulture and Horticulture recorded from all of its 139 participants that the offices with plants were more “pleasant, brighter and generally more interesting” (34). The vast majority also felt their ‘office biotope’ was more refreshing, made them feel less stressed and enabled them to concentrate better. The conclusion of the Bavarian study was a working atmosphere with this ‘office biotope’ was beneficial not only in improving people’s mood but also for their work. Another study conducted in Norway found that by adding plants, health complaints among workers decrease significantly; tiredness fell by 30 percent, sore throats fell by 30 percent, cough fell by 37 percent, and sore skin fell by 23 percent (Fjeld). Therefore, by bringing some greenery into the office, the employees and company will benefit not only by improved working atmosphere, but also by creating a “natural” environment that will improve the climate too (34).

**Ergonomic Control**

Work environments designed to enhance productivity will range from the architecture to office equipment. With the computer being one of the most widely used tools in companies, office equipment such as desks, keyboards and computer monitor screens, should be adjusted to the individual’s body to be ergonomic. Ergonomic means “the applied science of equipment design, as for the workplace, intended to maximize productivity by reducing operator fatigue and discomfort” (www.dictionary.com). Poor, non-ergonomic workspaces commonly create adverse long-term and short-term symptoms such as headaches and musculoskeletal disorders (MSDs). MSDs are injuries or illnesses such as sprains, strains, tears, back pain,
carpal tunnel syndrome, and hernia (BLS). The Occupational Safety & Health Administration (OSHA) stated in 1991; “Work-related musculoskeletal disorders currently account for one-third of all occupational injuries and illnesses reported to the Bureau of Labor Statistics (BLS) by employers every year. These disorders thus constitute the largest job-related injury and illness problem in the United States today.” “Common examples of ergonomic risk factors are found in jobs requiring repetitive, forceful, or prolonged exertions of the hands; frequent or heavy lifting, pushing, pulling, or carrying of heavy objects; and prolonged awkward postures. Vibration and cold may add risk to these work conditions” (Occupational Safety). The diagram below shows good working practices of a computer; Implementing a flexible ergonomic work program will help reduce work related injuries. No single arrangement of components will fit everyone.

Figure 3-2. Diagram of ergonomic practice. (Source: http://www.desertbusinessinteriors.com/ergonomic.htm. Last accessed February 2, 2010).
Office Layout

Despite popular belief, a survey by Gensler found 62% of U.S. office workers have great respect for leaders who work in an open plan environment with their teams rather than in private offices. Traditional offices of the past have been rigidly organized, often times revealing the structure of a company. The managerial positions tended to have their own windows facing outside which in turn blocks daylight inside the remaining work spaces. Meanwhile, the rest of the office workers worked in 6 foot tall cubicles that would cut any sort of distant view. This style of open floor plan still divided workers. People are shifting from a traditional mind set and are thinking of ways the office design can enhance collaboration and creativity.

Historically, a typical office configuration has 70-80 percent of the space dedicated to individuals, called “I” space. The remaining 20-30 percent is then “we” space. The Use Center Research, a group that writes articles on office organization, looked at themselves and found they needed a ratio of 30-40 percent of “I” space and 60-70 percent of “we” space (Tanis 10). Not all companies need to achieve the 30:70 ratio but it points out that “collaboration space is really key to supporting the knowledge-based culture. How you organize this “we” and “I” space can be solved through architecture.

In an ideal office layout, there would be a balance between “we” spaces and “I” spaces. This means that there would be a combination of quiet spaces, private offices, an open floor plan, formal and informal meeting spaces. The benefits for having collaborative spaces include having a sense of community, encourage better communication and improve information exchange among co-workers. It also allows intergenerational communication. This provides opportunities for the more experienced
workers to learn new ways to work or new technologies from younger co-workers while younger workers can receive less formal mentoring from working around those more experienced. Individual workspace, on the other hand, has privacy, less noise, more individual space, typically, and is seen as a status symbol (Kupritz).

Though there can be several ways to organize office space in an open floor plan, this thesis will narrow it down to four basic layouts according to Francis Duffy’s book “The New Office”: the Hive, Den, Club, and Cell.

![Diagram](http://www.emeraldinsight.com/fig/3080040101005.png).

**Figure 3-3.** A) Diagram describes the relationship between office typology and interaction (Source: Jaunzens). B) Diagram shows Duffy’s typical layouts of the four typologies (Source: http://www.emeraldinsight.com/fig/3080040101005.png. Last accessed March 21, 2010).

In the **Hive** layout, staff have little autonomy and little interaction. “The workstation style is uniform and relatively simple with rigid layouts. There is little opportunity for space use intensification e.g. hot desking as staff will rarely leave their desks” (Jaunzens 5). It gets its name from the beehives because workers are busy working. Then **Den** is more interactive and “the idea of team based work of a relatively straightforward and uniform kind, although requiring a mixture of different interdependent skills” (5). These
workers will more likely carry varied tasks than those in a hive. It is an office made for busy individuals that also have nearby places to interact informally as a team. The Cell is less interactive with more individual based work. Each desk is divided into its own room for concentrated study and privacy. The Club, which is seen used more often today, is a combination of all three office types and is typically composed of “a collection of highly autonomous people who require at times being highly interactive, but at other times to have their own space for concentrated individual based work, to match the varied tasks they carry out. It is a dynamic organization where there is an erratic and changeable occupancy pattern of individual and group settings to suit the needs of the market” (5).
CHAPTER 4
THREE BUILDING CASE STUDIES AND THEIR SUSTAINABLE TECHNOLOGIES

Reasons to Study Buildings

The decision to study highrises came about because the nature of high rises makes it difficult to make them sustainable because a lot of energy is used to power these buildings. It takes critical decision making skills when creating a typical floor plan and extra attention is needed to find ways to make them save energy since major details will be repeated. The architect must also consider satisfying everyone’s needs: the client’s needs, budget, and technical aspects. The choice to study high rises also came about because they are efficient in terms of minimize the building’s footprint on land and because they provide such a high ratio of rentable floor space per unit area of land. They also give identity to cities as icons. As the world becomes more urban, there will be a greater trend to develop high rise constructions. More attention should focus on saving energy in these large structures so architects can constantly improve on them as more are built in the future.

In narrowing down the buildings to study from, three were selected from Germany. Buildings were not picked from the U.S. because sustainable buildings are not the industry standard yet because certificates such as LEED are still just voluntary. Europe is generally perceived to be more progressive in sustainability than other developed countries. An example of its progressive approach is the EU Legislation, the Energy Performance of Buildings Directive 2002/91/EC (EBP Directive), which sets minimum standards for all new buildings and large renovations. Furthermore, Germany has created policies adding an extra notch in sustainability. Germany actively obeys their progressive government regulations to reduce their carbon footprint, such as Agenda 21.
and Energieausweis. Energieausweis is an energy certificate each building is required to have that evaluates its energy performance when it is sold or leased (DENA). Germany maintains strict building regulations on issues such as access to view a window and minimum light levels (See Page 28). Though this does not apply to the buildings selected, Germany has enforced an Energy Saving Ordinance since 2007 (EnEV2007) by the Deutsche Energie-Agentur - the German Energy Agency (DENA). These require that whenever a building is built, sold, or rented out, it will be valid for 10 years.

In addition, it was important to select buildings within the climate zone to make the temperature and humidity variables more comparable since not all buildings could apply the same passive heating/cooling strategies in different climates. The buildings’ location selected is characterized as “temperate and marine.” Generally, in Germany it is cool and cloudy, with wet winters and summers and occasional warm foehn wind (Climate-zone). Hannover has an average high temperature of 72ºF and average low temperature 28ºF (Climate-Charts.com). Frankfurt has an average high temperature 77ºF and average low temperature 28ºF (BBC Weather Centre). Essen’s average high temperature is 70.9ºF, average low temperature 31.5ºF (Climate-Charts.com).
Figure 4-1. Map of Germany with the cities selected buildings are in: Frankfurt, Essen, and Hannover. (Source: Jennifer Mackey).

Selecting buildings designed for employees was equally as important. Therefore, the three high rises selected found ways to connect people to one another, the building, and the external environment while giving a degree of control to the individuals. The buildings selected are: Commerzbank by Sir Norman Foster, Nord/LB by Behnisch, Behnisch & Partner, and the RWE Tower by Ingenhoven Architects. These buildings have been selected because they are innovative prototypes of sustainable highrises. The buildings not only consider energy but also deeply consider the workers inside it, taking into account their needs in order to make them more productive. While all buildings have similar features such as double glazed facades and use of daylight, they also approach their office layouts differently. These buildings are a good starting point in order to understand whether these sustainable high rises could be prototypes for future projects.
The relationship between buildings and occupiers is constantly changing, with frequent clashes between operational requirements and physical facilities. Designers seldom get feedback and typically only notice problems when asked to investigate a failure. To get some insight on the building’s performance as a tool for productivity, a survey was created and passed out to office workers working inside these three buildings. The surveys ask employees to rate certain features of the building. Getting feedback on employees’ experiences is invaluable in developing shared understanding and will help architects understand what improvements could be made in order to enhance employee performance. For example: if there’s too much glare, then more screening devices need to be added; or if it is too noisy, sound absorbing materials should be used; or if there’s not enough natural daylight in certain parts of the building, more transparent materials should be used. Since the typical floor plan of an office high rise is repeated several times, it is important to design it right the first time. The hypothesis will be that all these buildings will generally be rated satisfactory/neutral in the questions asked but each will need minor improvements, even on their sustainable features. The feedback and data from surveys will provide clues to find better solutions.

Commerzbank by Sir Norman Foster, Frankfurt

“The form of the building is strongly influenced by energy considerations.” - Sir Norman Foster (Fischer 9)

Commerzbank has the reputation of being one of the first ecological high rises in the world. It was built in 1997 with design features made to save energy and with innovative features defying traditional work environments. The tower has operable windows and a high level of transparency to promote natural daylight and social visual contact. Other innovative features include winter gardens spiraling up the tower and an
atrium running throughout the entire tower. The building consumes half the energy levels than conventional office towers (Foster + Partners 2007, 118). The base of the tower is filled with program such as “27 dwellings with a total area of 4500 m², a bank, shops, office, and a multi-story garage for 300 cars and 200 bicycles” (Fischer 11). Its 53 stories of office and multifunction floors make it an icon for sustainability for the city of Frankfurt

Figure 4-2. Commerzbank tower maintains the scale of the block at the base with restaurants and cafes (Photo: Jennifer Mackey).
Figure 4-3. A. Section of Commerzbank tower. (Source: Fischer 22). B. Site plan of Commerzbank showing public restaurant, entrance, and public amenities. (Source: Fischer 20).

Ventilated Skin

The double skin façade is a feature Commerzbank and all the other buildings selected for this thesis have. Double skin facades allow occupants to open windows for fresh air without the effect of draft winds associated with high elevations. Every office in the building has access to its own operable window which enables occupants to control
their environment. The aluminum curtain walls are double glazed with an "integrated sun protection and can be controlled both by the central control system of the building and the individual employee" (Fischer 13).

Figure 4-4. A) a. steel structure, b. glazed partition, c. sprinkler, d. convection heater, e fire protection, f. raised floor, g. lightweight concrete floor, h. suspended ceiling, j. movable double-glazed window element. K. fixed outer glass, l. enamel-coated glass sprandel, m. air-intake transom, n. air-exit transom, o. lighting, p. glass cover. (Source: Fischer 27). B) Detailed section of external windows. Ventilation slots above and below each window supply fresh air. When windows cannot be opened, fresh air is introduced via supply ducts in the ceiling. The air is slightly cooled in summer and heated in winter, but only to maintain a sense of freshness or to reduces draughts. (Source: Foster 2007, 76).
Offices in the outer perimeter of the tower are ventilated naturally from the exterior air. Offices on the atrium side are ventilated from the gardens which draw air directly from the outside through ventilation flaps. Although the mechanical ventilation is proposed only for days with extreme temperatures (Fischer 17), occupants from the building reported mechanical ventilation is used majority of the time.

Figure 4-5. Section through the tower showing typical office floors and gardens. (Source: Foster 2007, 24).
Temperature Control

As a means to save energy and maintain thermal comfort, the building features an “Intelligent” building-control technology. This feature controls the air quantities pumped in or out of the building and even cuts air supply to unoccupied spaces. Commerzbank tower also uses water, instead of air, to condition the building, which saves energy over the life of the building. It also controls direct solar heat gains by controlling the external shading located inside the double glazed façade. The building control system is also activated while the building is not used at night or during holidays. For example, the building could be naturally cooled during summer by opening the windows at night (Evans). “Office design temperatures are 20°C minimum in winter and 27°C maximum in summer” (Evans).
Figure 4-7. A) When weather conditions are suitable, all the Commerzbank’s offices are naturally ventilated. Under these circumstances, the building’s mechanical ventilation and cooling systems close down automatically. (Diagram: Jennifer Mackey). B) Picture of a typical window opened. (Source: Foster 2007, 76).

Heat during winter months is supplied by conventional fixed radiators at the side of the windows. For hot summer days, the building is cooled “by a static water filled cooling system” (Fischer 17). “The pumped cold water needed for cooling is produced by environmental-friendly absorption-type refrigerating machines attached to the municipal steam networks” (17). Since heating and cooling at not controlled by “air only systems,” the air exchange rate can be reduced to the required minimum with the outside air being used exclusively. Energy is further saved with the façade’s high heat insulation quantity. Thus, 25% to 30% less energy is used than in comparable conventional buildings (17).

**Daylight**

Natural daylight is maximized with the tower’s glass façade, transparent partitions between offices, and the atrium. As a result, all offices have access to natural
daylight. Transparency is also used as the supreme principle for a “sense of mental openness to a working world based on communication” (Fischer 15); a concept clearly made in these visually open offices. The level of transparency creates a “meta-atmosphere of trust,” (15) a characteristic of creative work. This works well as banking is becoming an ever more creative profession.

Figure 4-8. A) Office in the north core "panoramic office." (Source: Fischer 69). B) Natural Daylight enters each office in the building, including in the interior offices. (Source: Fischer 68).

Figure 4-9. Glazed partitions and light reflective materials allow daylight to reach all offices and give visual access to colleagues. (Source: Fischer 66, 67, 73).

Artificial Lighting

The lighting system in the offices is suspended fluorescent tubes regulated with light sensors. The light sensors determine the amount of daylight from the façade and
will adjust according to a prescribed set value which is implemented by a dimmable electronic ballast device (Evans). Corridors and offices lit with continuous light are automatically switched by movement detectors (Fischer 19). The overall systems work to ensure adequate light levels of energy efficiency with the dimming control rather than the switching on and off system.

**Organization**

Figure 4-10. Typical floor plans at the completion of the tower with team and combi offices. (Source: Fischer 21).

Most offices at the time of completion used the combi office layout. Recent reports from the employees have said many offices have converted to the open floor plan in 2009 due to the recent merge with another company. The floor plan also offers team offices. The walls between access corridors and the offices are glazed at the architect’s request. The glazed walls permit daylight and open up views through the building of “wide angle perspectives” as the architect intended. More importantly, the partitions enhance collaboration from the visual connection among employees (Fischer
13). All core functions of the building (stairwells, elevators, mechanical) have been pushed to the corners in order to make way for the atrium.

**Winter Gardens**

From the street view, one can easily distinguish the location of the sky gardens spiraling around the building with the different glazing system from the offices. A garden takes up one arm of the triangular plan for the four floors. Then, the next garden shifts round to the next arm. The gardens bring daylight into the central atrium and are said to make socially “village-like clusters of offices” (Foster + Partners). Each office cluster is four stories. These ‘gardens in the sky’ play an ecological role for fresh air, places to relax during breaks, and informal meeting spaces. People working in the inside offices of the other two arms can look across the atrium into the gardens for visual break, and beyond through the structural glazed screens to the city. Their landscaping “reflects the directions they face – Asian, Mediterranean or North American. For [the] Commerzbank staff these spaces offer an extra dimension to the workplace” (Evans). The gardens are set to a minimum temperature of 5°C and are warmed when necessary with exhaust air from the offices (Evans).
The triangular atrium originally was envisioned to be open. This would have created a giant chimney with air being exhausted out of the top of the building in a stack effect. It would have resulted in an undesirable updraft and accumulated heat at the top. The solution was to segment the atrium every 12 stories. The atriums help from an energy point of view too for a building using natural ventilation for some of the year. (Davies).
Figure 4-12. A) View from lobby of Atrium at night (Source: Jennifer Mackey). B) Fire Stopper segments atrium. C) View of atrium from top of tower with views of gardens. (Source: Foster + Partners 2007, 58).

**Nord/LB Hannover by Behnisch, Behnisch and Partner, Hannover**

“In our opinion it was important to develop an unmistakable formal language for the functions of the external areas and to respond to the clear character of the architecture.” - Behnisch (Flamme-Jasper 98)

Figure 4-13. View of Nord LB Building in Hannover at dawn from across the street (Photo: Jennifer Mackey).
Norddeutsche Landesbank (abbreviated Nord/LB) is one of the largest commercial banks in Germany. The company set up a design competition for their new headquarters in Hannover, one block by the prominent, historical city hall of Hannover. The winning design was won by Behnisch, Behnisch & Partner, whom originally designed the building without the tower. Later, it was decided to add the tower. Completed in 2002, the building formally hugs the entire edge of the block giving it a traditional block resemblance with a featured glass curtain façade. Inside the block there is a public courtyard with a few shops and restaurants on the street level. A distinctive tower rises 80 meters from the center of the courtyard (Reynolds 113). The form of the tower has a twisted, irregular expression of floors stacked on top of each other. Its geometry conforms to nothing in its surroundings. The tower’s form is in response to the historical geometries of the north (Behnisch Architekten1).

![Cross section of the building.](image)

The building is more famously known for its ecological concepts. A vast portion of it is naturally ventilated with a double façade. The building also has many added features, some being high tech while others basic passive strategies, to save energy.
and resources. Some of its features include use of natural daylight, geothermal heating, reflection pools, green roofs, and rainwater collection.

Figure 4-15. Left: Plan of third floor plan showing typical offices. Right: Plan of sixth floor. (Source: Flamme-Jasper 83).

**Natural Ventilation**

Depending on the direction and requirement of the surrounding area, the office facades are built in a variety of ways. Rather than relying solely on fresh air intake from conventional air conditioning, all rooms in Nord/LB have an operable window for fresh air (Flamme-Jasper 57-58). Air from the outside enters the exterior window and then enters through another flap window between the office and corridor. The air then exits through the fan-powered vent stack located in the hallway which pushes the air up out of the building.
Figure 4-16. A) Simulation of the natural ventilation system. (Source: Flamme-Jasper 102). B) Vent stacks in hallways have slits to intake exhaust air (Photo: Jennifer Mackey).

Where applicable, the building is skinned with a double façade in order to protect employees from the wind, noise, and vehicle emissions. This occurs towards Friedrichswall, WillyBrandt-Allee, and the Theatre am Aegi (Flamme-Jasper 57). The inner courtyard and side facing the surrounding residential areas do not need the double facade (59). The façades for the eighteen-storey tower block however need particular demands. Stronger winds from the high elevation and intense heat from the sun have to be considered. For those areas a double facade and special solar protection features were installed. The tower is formed by the steel and glass tip in a futuristic way. “Glass surfaces of different sizes lead the vertical emphasis of the tower on upwards” (59).
Figure 4-17. A) Typical operable window in office provide natural ventilation. B) Double skin façade from tower. (Photos: Jennifer Mackey).

**Natural daylight**

A high level of transparency is used throughout the skin of the façade. This gives the building an open and friendly character from its unusual geometric shapes and the materials used. The tower, compared to the rest of the building, is much more exposed to the direct rays of the sun. For this reason, a solar protection system was integrated into the space between the double façade on the south-east side. In the other areas there are highly reflective sun blinds and anti-dazzle blinds situated internally which follow the sun and control the daylight. They are concave-shaped layers of aluminum and direct the light deep into the room (73).
Figure 4-18. A) Screens in typical office reduce glare. (Photo: Jennifer Mackey). B) Strings hanging down and horizontal blinds control light levels in a conference room. (Photo: Jennifer Mackey)

There are also, however, areas in the building where sunlight never reaches, such as the main entrance area beneath the tower. The fully glazed entrance hall, for example, is therefore given additional lighting by heliostats. The heliostats are located on the perimeter roof area where they reflect the sunlight into the inner courtyard, into the water basins, and into the hall. The narrow high area between the historical Siemens buildings and the new building is treated in similar fashion, since this glass-roofed access area hardly receives any sunlight down to the ground floor. With heliostats and fixed mirror elements in the new building occupants benefit with supplemental vitamin D from the supplemental sun rays.

The building was so conceived that, independently of the available indirect lighting of the room and the direct lighting of the work-stations, all employees can work as much as possible in daylight. For the office rooms in the perimeter block a special solar protection system was developed for the outside rooms, equipped with slats set at two different angles. It automatically adapts to the current positions of the sun, and, due to
the special angle of the upper third of the slats; even when closed there is enough daylight reflected onto the ceiling to be sufficient for working (72). In order to give the employees the greatest possible measures of freedom, the solar protection system can also be manually operated. The different depths of the rooms, varying from five to seven meters, enable one to experience the changes in daylight even in the corridor areas and create a flood of light throughout the building.

Figure 4-19. A) Typical office at night. (Source Nord LB). B) Heliostat on the building perimeter. (Photo: Jennifer Mackey).

Figure 4-20. Control gauges for artificial lighting and blinds are by doors. (Photos: Jennifer Mackey).
Green Roofs

Figure 4-21. Roof plan indicating gardens and pool. (Source: Flamme-Jasper 84).

The concept of the exterior was worked out by the Behnisch office while the execution was carried out by Landscape Architects Prof. Nagel Schönhoff + Partner. The inner courtyard next to the large sloping glazed surfaces of the communal areas was intended to not be naturalistic like the nearby park, Maschpark, “but rather an architectural landscape with three lakes adjacent to each other” (62).

Though the gardens are not seen by the public, it is seen by the employees of the building in order to “feel good in the building” by seeing something pleasant and atmospheric. The roofs are “planted with greenery” (66) and are a way to soften the view of the roof tops. The roofs are constantly maintained to keep a beautiful floral display and are watered by an automatic drip watering system. Other roofs on the perimeter block and the twisted roof of the tower exhibit the extensive greenery. Here the roofs have different varieties of drought-tolerant sedum over wise areas so plants are relatively undemanding and require only little care. Their colors vary between yellow, blue, and red. Because the architects have designed each storey to also have a
direct link to the outside via terraces, employees can enjoy this pleasant view not only from the window. Even the view to the originally unattractive transformer station has been interestingly fashioned. While it was enhanced visually at ground level by wood paneling and an illuminated wall, from above it looks more like a park than a building. The roofs of the individual parts of the building were covered completely in greenery and large trees were also planted.

Figure 4-22. A) Green roof. (Source: Flamme-Jasper 97). B) Dense greenery on the staff restaurant. (Source: Flamme-Jasper 97). C) Roof garden in winter (Photo: Jennifer Mackey).

Courtyard

The courtyard is a semi-public area for employees and the public to enjoy. It buffers sound and polluted air, serving as an urban oasis from the Hannover traffic. Here, there was no need to take into consideration the high demands regarding sound
proofing and air-pollution, and so double facades were not necessary in this area. It serves as a “duct transferring clean air from the central courtyard to the individual offices” (Behnisch Architekten 1).

Reflection Pools

The pool in the courtyard has many useful purposes. Its primary purpose is to collect rainwater for plant irrigation. It also serves as a microclimate controller for cooler air in the courtyard and as a means to reflect light into the building (Behnisch Architekten 1). The whole inner courtyard, including the water basins, is paved in natural sand-colored stone slabs made of travertine in a unified way. In winter, when the lake’s water is drained because of frost, the stone plaza increases in size and pedestrians can walk across the shallow basins, where they would normally walk over a footbridge (Flamme-Jasper 62).

Figure 4-23. A) Reflection pool in courtyard. (Source: Flamme-Jasper 65). B) Pool drained and frozen in winter (Photo: Jennifer Mackey).
Office Layout

Above the public area, on the ground-floor level, is the beginning of the interior working areas. The complex was planned in this way so offices with economical floor plans could be created everywhere. Since the shell is jointless construction of reinforced concrete, more stiffened walls could be allocated. The architect used a recurring planning grid of 1.5 meters to allow for flexible use of the building. The individual parts of the building have varying office depths, so several types of office could be realized: open-plan, private, cellular, combined, or shared.

Figure 4-24. A & B) Office corridors with transparent partitions. (Photos: Jennifer Mackey).

Furniture for working areas has been designed by the Behnisch office. Between the typical individual work spaces, there is a customized, double-sided cupboard serving for storage and as a wall partition. The top portion of the cupboard is made of glass to further distribute more natural daylight inside the building. The furniture was designed to be functional and ergonomic, while also creating space (68). Walls to the corridors and exterior side are transparent glass. The abundance of transparency creates desired openness, generous flow of light, and an ease of communication.
Window ledges are placed at a certain height so even people sitting have a view from their desk into the distance and sometimes downwards. Offices and other spaces are painted white with bright accent colors for a pleasant, bright working atmosphere (67). The common accent colors are yellow and blue, while the shades of the cupboards are delicate and light. Colorful artwork throughout the building enhances the positive atmosphere.

The impression of long corridors was avoided by creating special areas or little foyers set at sensible intervals near the stairwells, providing a rhythmic flow to these corridors (68). On different floors, many recreational rooms, open-plan offices, or tea-kitchens have greenery or wood terraces in front of them. Terraces on each floor can be used by the employees during their breaks, giving structure to the building and offering places for viewing the city, City Hall, and Maschpark. These terraces also provide a link to the inner courtyard.

Figure 4-25. Kitchenette with clearly marked recycling bins help break the long corridors. (Photo: Jennifer Mackey)

**Geothermal heating**

To further reduce energy costs, geothermal heating is used to preheat warm air from the 20 meters tubes below the ground. Heat exchanger tubes in the building's
1,220 foundation pilings heat or cool water as required by the season. The water then circulates through polyethylene pipes in the building floor structure to activate the floor slab as a thermal mass. Performing as a thermal storage bank, the geothermal system balances heat supplied to the ground during the summer and extracts from it during winter. The only electric power required in the geothermal system stems from the circulating pump balancing the amount of heat admitted to, and extracted from, the soil (Flamme-Jasper 98-104).

Figure 4-26. Computer screen showing the geothermal monitoring. (Photo: Jennifer Mackey).

Artificial Lighting

Development of the interior lighting plan was conducted in tandem with the exterior illumination. Particularly interesting for the long distance effect is the tip of the high-rise building, whose specially layered blue-yellow glass elements change in color according to the amount of light and the position of the viewer, even in the daytime. At night, the tip acquires a quite different quality through powerful white and blue LED illumination integrated into the construction. The illumination of the tower is completed, amongst
other things, by the illumination of a stairwell, some protruding elements, and the wall surfaces in corridors. The concept of vertical lit surfaces continues into the ground (78) floor area of the perimeter block, whereby the main entrance is highlighted additionally with floodlights on the ground. Through the illumination of the rear walls in the staff restaurant, in the cafeteria, and in the entrance hall, the inner courtyard becomes transparent and thus, is also seen in the evening from Friedrichswall (79).

**RWE Tower by Ingenhoven, Essen**

**First Ecological High Rise**

The RWE AG Tower became Germany’s first ecological highrise when it was completed at the end of 1996, just before Commerzbank in Frankfurt opened. The design was inspired after RWE’s request to make an office that would create employee and visitor comfort, clarity and style, building incorporation into the city plan of Essen, and individual control of natural light, temperature, and ventilation. Its highest priority, though, would focus on energy. As a result, it has a double skin façade so employees may open windows, solar panels, and other mediums to save energy (Bridgleb).
Figure 4-27. A) Ground Plan: 1. elevator lobby, 2. glass elevators, 3. connecting stairs, 4. foyer, 5. cafeteria, 6. restaurant, 7. bar, 8. dining room, 9. serving point for meal, 10. kitchens, 11. lounge, 12. conference rooms, 13. light well, 14. lake-side terrace, 15. lake, 16 RWE park. The garden level links the tower with the RWE parks and gardens. A natural difference in height allows the tower's park-side basement to be lit by daylight. All restaurant and conference rooms are organized in a ring around the tower's circular plan.” (Source: Bridgleb 36). B) Street level view of RWE from a block away. (Photo: Jennifer Mackey)

**Natural Ventilation**

It was always envisioned office workers would be able to open the windows for ventilation, physiological, energy reduction, general wellbeing, and employee satisfaction reasons (76). The advisors for the transparent façade, Gartner Façade Specialists, were commissioned to design, deliver, and install the façade. The offices would be ventilated naturally via a double-layer façade on weather permitting days. The
solution was to create the double-glazed façade “with a 50-cm wide space between the two glass walls referred to as a ‘façade corridor’” (63). The exterior window assembly “is made of flint glass that is fastened in only eight places” (63). The inner windows, which were designed as sliding windows, extend from the floor to ceiling.

In order to make them user-friendly, a wheel opens the window by varying degrees when turned. The glass is fitted with a high translucent insulation laminate with k-value of 1.2 W/m²K. This provides good heat insulation in winter and, in combination with slatted blinds, effective sun protection in summer (63). In order to ventilate the façade, diagonal air streams were created within the “façade corridor”, requiring the supply and extracted air sections to be arranged laterally. Hence, the façade perforates the under and upper sides and outer glass walls. An effective section is achieved with 120 mm wide vents. “The limited outer supply air vents and the perforation of the platform panels act as a wind-breaker to oncoming wind, thus preventing disruptive draught when windows are opened, even at considerable heights” (64).
Figure 4-28. Isometric view of the façade. Facade details were examined and optimized using a large number of samples and mock ups. To obtain planning permission for individual parts of the façade, crash-resistance trials with a pendulum ball were conducted. (Source: Bridgleb 68).

Figure 4-29. A) Section view of the façade. (Source: Bridgleb 63). B) Façade detail. 1. façade construction 2. façade segmentation 3. supply and extracted air vents 4. sun protection blinds 5. sliding window 6. thermal separation 7. anti-glare device 8. convector 9. walking platform. (Source: Bridgleb 64).
Individual Temperature Regulation

Each individual office could be naturally ventilated from the double skin facade. Even more ideal, all offices could each control their own temperature with a thermostat. At the client’s request, the team had to come up with a way for each office to have its own temperature regulation. After much testing, it was decided they would use cooled girders and mechanical ventilation. The final design resulted in a surfboard-like shaped installation with fins placed in the ceiling of each office. Cool water runs in the pipes to cool down the office. This “surfboard” is only used on floors leading up to the 18th floor (the technical floor). The floors above would not be applicable to this cooling installation because the cooling loads are higher for rooms such as dining conference rooms. Those rooms have the same surfboard concept; however, the ducts and diffusers are integrated inside (Bridgleb 74).

The offices in the tower and peripheral building use a convector heating system. The heat is supplied by the district heating network of the city of Essen. The heating supply is indirect as it comes from three district heating transfer points. The distribution of heating water is set up in a two pipe system from the central transfer unit on the 3rd floor via pumps (pressure differential- controlled). It then travels to the central climate control-units on level -3 and to the technical installations floor (T1) in the tower (81). Public areas use an air system of ducts integrated into the ceiling’s concrete structure to cool and heat the spaces. The cooled air flowing through the ducts also cool the concrete mass, further stabilizing the ambient conditions in the room (75).
Natural Daylight

Natural daylight is accessible in every office and conference room on the conference level. The conceptual idea of the client to create a highly transparent skin was generated by the idea of harnessing as much daylight as possible inside the tower. The double skin glass façade is made with sun protector slats and semi-translucent textile anti-glare screens to control daylight according to the worker’s need. This is effective in many ways to address challenges with interior blinds, including reducing solar heat gains. The circular plan also allows the office to “have a larger surface area towards the windows” (44). The interior walls, glazed at the top, further permit more natural daylight to enter inside the building center. Even the glass dome atop the building, storey-height glazed windows and auxiliary zones, such as technical supervision, communication and technical installation benefit from virtually unrestricted
daylight (48). The glass dome, a raised circular steel structure with aluminum slats and extended glass screen divert the direct sunlight from the circular conference room below (49).

Figure 4-31. A) Glazing of typical office (Source: Bridgleb 63). B) Lever to open windows. (Source: Bridgleb 63)

Figure 4-32. Daylight can be diverted and dimmed thanks to the sun protector blinds inside the double layered facade and the interior anti-glare screen. (Source: Bridgleb 64).

**Artificial Lighting**

The office lighting concept is designed with a day and night setting for maximum comfort. The settings can be activated by the occupants. At night, illumination is provided with downlights producing a warm white light. In order to minimize any
unwanted vertical dazzle when looking directly into the lights from below, the lights have been fitted with special diffusers. Special reflectors in the lights also minimize direct glare (87). During the day setting, involute lamps are use to complement natural daylight with a neutral white light. “Involute lamp technology helps to minimise reflective glare. All lighting systems are integrated flush into the technical duct in the ceiling which also accommodates sprinklers, loudspeakers, etc.” (87).

Figure 4-33. A) Sun protector blinds and antiglare screens on the glass work together to regulate the daylight and artificial lighting. B) Typical office facing the hallway with the glazing on top of the cabinets and door. C) Typical office with wood interior cabinets. D) Office space. E) Conference room (Source: Bridgleb 44-114).
Office Organization

The plan of a typical office floor is circular with individual offices hugging the outer edge. The elevator core was moved outside to enhance communication within the building, rather than having a solid core creating a block between offices. The inner circle of the plan has spaces such as conference rooms, restrooms, storage, mechanical space, and staircases. Every so often, the ceiling is cut out for glazed interior stairs, linking user zones stretching across several floors. “Recreational areas and lounges are located in the interior zones along with the relevant catering service equipment” (47). This promotes communication amongst different levels, unlike the typical stacked floor plans of typical high-rises. It also encourages less use of the elevator as people will be inclined to use the open stairs to access nearby floors. By
placing the building’s cores to the sides, the lobby at ground level also has a grand free center space.

Figure 4-35. Typical floor plan of conference level (Source: Bridgleb 46).

Figure 4-36. Typical corridor (Source: Bridgleb 44).
Method of Survey

In order to gain insight into what working in the selected office buildings is like, a survey was created for employees working in the actual buildings. The data collected by the surveyors, Jennifer Mackey and Lorenzo Pagano, can be divided into subjective and objective variables. The objective variables measured include gender, age, career position, office location (proximity to windows and exterior walls) and average working hours per day. The subjective variables measured include occupant satisfaction and self-reported ratings with the indoor environment quality in following categories: thermal comfort during different seasons, ergonomics, lighting, acoustics, and overall satisfaction with building. In satisfaction and self-reported rating questions, a 7-point semantic differential scale with the endpoints “very unsatisfactory” and “very satisfactory” were used. For the purposes of comparison, we assumed the scale is roughly linear, and assigned ordinal values to each of the points along the scale, from -3 (very dissatisfied) to +3 (very satisfied) with 0 as the neutral midpoint. Wherever possible, other questions rating qualitative aspects of the building are also descriptive polar terms. For example, question four asked “How would you rate the natural daylighting in your office space?” The endpoints are “too dark” or “too bright,” rather than “very satisfactory” or “very unsatisfactory.” Thus, we could better understand if there is a problem with the light levels and then were able to infer the cause. At the end of the survey, surveyees could write what parts of the building they wish to change in order to better understand what features of the building need improvements. Of the three buildings surveyed, all are located in northwestern Germany. Each is relatively in
the same moderate climate characterized by “gentle, warm summers and mild winters” (germany.com).

For access to the buildings, permission was requested to perform the surveys through the respective human relations or the communications department. If permission was not granted, as in the case of the RWE Tower, then the surveyors asked the office workers to fill out the survey on public property. In the case of Commerzbank, permission was granted to fill out surveys in the public areas such as the lobby and restaurant. In Nord/LB, access was granted in the semi-public areas until the surveyor was told to discontinue. Due to the time limit in Europe, all surveys were conducted during winter which may have an influence on the responses concerning temperature. The cold weather may have also limited the amount of responses people were willing to give. An attempt to fill out at least 30 surveys was made for each building. The only qualification to fill out the survey was the employee have an office within the building. All people surveyed represent a wide range of careers, including: receptionists, interns, accountants, analysts and managers.

The survey was carefully worded to not create biased opinions with negative connotations. For example, instead of asking about “noise levels” of room, which usually is a negative term, the surveyed are asked about the “sound level” of their work environment. The questions are also worded as simple as possible in order to avoid miscommunications and cultural misunderstandings. For example, instead of using the word “Fall” as a season, people in Europe generally use the word “Autumn” instead. For office workers who prefer to read in German, a German copy of the survey was available. The survey was 18 questions, with a variety of “fill in the blank” and close-
ended questions. Many of these high profiled workers had to attend meetings or had limited time for lunch, so keeping the survey to a five minute time limit helped to obtain a greater number of completed survey responses.

**Semantic Differential Scale**

When formatting the questions, it was decided the Semantic Differential Scale would be the most practical scale to use for respondents to provide their ratings. The Semantic Differential Scale is a seven point scale with end points associated with bipolar labels. Bi-polar means two opposite streams are used; in this case, “very satisfied” and “very unsatisfied.” In other cases, bipolar adjectives are used, such as “too loud” or “too quiet.” The Semantic Differential Scale is used to develop an image profile. It provides a good basis for comparing images of two or more items. The big advantage of this scale is its simplicity, while producing results compared with those of the more complex scaling methods. The method is easy and fast to administer, it is highly versatile, reliable and generally valid. It is also sensitive to small differences in attitude. Mean and medians collected from the scores can help determine overall similarities and differences between buildings. The scale used has a score between -3 to 3, rather than 1-7.

The survey was influenced by the Center for the Built Environment (CBE) Occupant Indoor Environmental Quality (Ieq) Survey. The CBE is at the University of California, Berkeley. It is an anonymous, invite-style survey measuring occupant satisfaction and self-reported productivity with respect to nine environmental categories: office layout, office furnishings, thermal comfort, air quality, lighting, acoustics, cleaning and maintenance, and overall satisfaction with building and with workspace. Their survey also asks respondents for a follow-up regarding a “dissatisfied” answer for any
question. Because of the limited time surveyees have to fill out the survey, this survey did not ask for follow-up for all questions. Instead, the end of the survey provides an opportunity for the respondent to indicate what they would change about the building.
Sample Surveys

School of Architecture

Building Evaluation
RWE AG Tower, Essen

University of Florida
Gainesville, FL 32611

Informed Consent
Protocol Title: Building Evaluation in Sustainable High Rises

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study:
The purpose of this study is to understand how features in the building affect your work environment.

What you will be asked to do in the study:
You will be asked to a series of questions about the office environment in which you work in. The questions are formatted in short response and a number rating system. All questions are related to the location of your work space.

Time required:
5-10 minutes

Risks and Benefits:
There are no known risks or immediate benefits to the participants.

Compensation:
No compensation is offered for participation.

Confidentiality:
Your identity will be kept confidential to the extent provided by law. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file in my faculty supervisor's office. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

Voluntary participation:
Your participation in this study is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:
You have the right to withdraw from the study at anytime without consequence.

Whom to contact if you have questions about the study:
Jennifer Mackey, Graduate Student, School of Architecture, Gainesville, FL 32611, email: jenmack@ufl.edu
Professor Maze, Assistant Professor, Assistant Director, School of Architecture, Gainesville, FL 32611, email: maze@ufl.edu

Whom to contact about your rights as a research participant in the study:
IRB#02 Office, Box #2250, University of Florida, Gainesville, FL 32611-2250, phone 1-352-392-0433.

Agreement:
I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant: ___________________________ Date: ___________________________

Principal Investigator: ___________________________ Date: ___________________________

Jennifer Mackey
1. What zone of the building is your workspace? (Floor number and please mark on typical floor plan)

2. How would you rate the thermal comfort during these times of year?

- **Summer**: cold -3 -2 -1 0 1 2 3 hot
- **Autumn**: cold -3 -2 -1 0 1 2 3 hot
- **Winter**: cold -3 -2 -1 0 1 2 3 hot
- **Spring**: cold -3 -2 -1 0 1 2 3 hot

3. How would you rate the humidity during these times of year?

- **Summer**: dry -3 -2 -1 0 1 2 3 humid
- **Autumn**: dry -3 -2 -1 0 1 2 3 humid
- **Winter**: dry -3 -2 -1 0 1 2 3 humid
- **Spring**: dry -3 -2 -1 0 1 2 3 humid

4. How would you rate natural **day lighting** in your office space? (diffused light, sunlight, etc)

- **Light Levels**: too dark -3 -2 -1 0 1 2 3 too bright
- **Glare** (computer screen): very unsatisfied -3 -2 -1 0 1 2 3 very satisfied
- **Controllability**: very unsatisfied -3 -2 -1 0 1 2 3 very satisfied

5. How would you rate the artificial **lighting** (task lamps, ceiling lights, etc)?

- **Light Levels**: too dark -3 -2 -1 0 1 2 3 too bright
- **Glare** (computer screen): very unsatisfied -3 -2 -1 0 1 2 3 very satisfied
- **Controllability**: very unsatisfied -3 -2 -1 0 1 2 3 very satisfied

6. How would you rate the sound levels (background noise)?

- **Sound Level**: too loud -3 -2 -1 0 1 2 3 too quiet

Please list factors influencing sound level: 

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7. Is view to "green space" important to you while you are working? _________________

8. How would you rate your access to view green environments (view of gardens, trees, etc)?
   
   | very unsatisfied | -3 | -2 | -1 | 0  | 1  | 2  | 3  | very satisfied |

9. Is the office organized in a way that supports collaboration and creativity?
   
   | very unsatisfied | -3 | -2 | -1 | 0  | 1  | 2  | 3  | very satisfied |

10. How would you rate the ergonomics of your workspace (desk, chair, keyboard and computer monitor adjusted to your needs)?
    
    | very unsatisfied | -3 | -2 | -1 | 0  | 1  | 2  | 3  | very satisfied |

11. How do you feel after work?
   
   | tired | -3 | -2 | -1 | 0  | 1  | 2  | 3  | energized |

12. What improvements would you make to the building? ____________________________
    
    ____________________________

13. What is your age? ______

14. Sex: female / male

15. Average working hours per day? _______ hours


17. Rate job satisfaction?
   
   | very unsatisfied | -3 | -2 | -1 | 0  | 1  | 2  | 3  | very satisfied |

18. On average, how many sick days do you use per year? ______

19. Overall, do you think the building enhances productivity?
   
   | strongly disagree | -3 | -2 | -1 | 0  | 1  | 2  | 3  | strongly agree |
Inkenntnissetzung

Protocol Betreff: Evaluation von Gebäude in kontinuierlichem Anstieg

Bitte lesen Sie dieses Dokument aufmerksam bevor Sie sich zur Teilnahme der Studie entscheiden

Grund der Forschungs-Studie:
Diese Studie wurde gemacht um zu verstehen wie die Eigenschaften eines Gebäudes ihre Arbeitsumgebung beeinflussen.

Was wird in dieser Studie von Ihnen verlangt:
Wir werden Ihnen eine Serie von Fragen bezüglich Ihres Arbeitsumfeldes stellen. Der Fragebogen ist auf kurze Antworten und nach einem Nummer-Bewertungsverfahren aufgestellt. Alle Fragen beziehen sich auf Ihr Arbeitsumfeld.

Durchführungs-Zeit:
5-10 Minuten

Risiken und Begünstigungen:
Es gibt keine bekannten Risiken und Begünstigungen für den Teilnehmer.

Abfindung:
Es wird keine Abfindung angeboten.

Vertraulichkeit:

Freiwillige Beteiligung:
Die Beteiligung an der Studie ist Freiwillig und es gibt in keiner weise Nachteln oder Strafen wenn Sie nicht Teil nehmen.

Ausscheidungs- Recht:
Sie können sich zu jederzeit aus der Studie zurückziehen.

Wer wird kontaktiert zu eventuellen Fragen der Studie:
Jennifer Mackey, Graduate Student, School of Architecture, Gainesville, FL 32611, email: jentwin@ufl.edu
Professor Maze, Assistant Professor, Assistant Director, School of Architecture, Gainesville, FL 32611, email: maze@ufl.edu

Wer wird kontaktiert für Fragen über Ihre Rechte als Teilnehmer der Studie:
IREB02 Office, Box 112250, University of Florida, Gainesville, FL 32611-2250, phone 1-352-392-0433.

Vereinbarung:
Ich habe die beschriebene Prozedur gelesen und bin einverstanden, freiwillig an der Studie Teil zu nehmen und habe eine Kopie der Beschreibung bekommen.

Participant: ___________________________ Date: ______________________
Haupt Ermittler: ___________________________ Date: ______________________

Jennifer Mackey
Die folgenden Fragen beziehen sich auf das Direkte Arbeitsumfeld Ihres Büros.

1. In welcher Zone befindet sich Ihr Arbeitsplatz?

2. Wie würden Sie die Temperatur in Ihrem Arbeitsreich während den Jahreszeiten bewerten?
   - Sommer: (-3) günstig, (-2) mittelmäßig, (-1) unangenehm, (0) neutral, (1) angenehm, (2) beengend, (3) unangenehm
   - Herbst: (-3) günstig, (-2) mittelmäßig, (-1) unangenehm, (0) neutral, (1) angenehm, (2) beengend, (3) unangenehm
   - Winter: (-3) günstig, (-2) mittelmäßig, (-1) unangenehm, (0) neutral, (1) angenehm, (2) beengend, (3) unangenehm
   - Frühling: (-3) günstig, (-2) mittelmäßig, (-1) unangenehm, (0) neutral, (1) angenehm, (2) beengend, (3) unangenehm

3. Wie würden Sie die Feuchtigkeit während den Jahreszeiten bewerten?
   - Sommer: (-3) zu trocken, (-2) ungünstig, (-1) neutral, (0) günstig, (1) zu feucht
   - Herbst: (-3) zu trocken, (-2) ungünstig, (-1) neutral, (0) günstig, (1) zu feucht
   - Winter: (-3) zu trocken, (-2) ungünstig, (-1) neutral, (0) günstig, (1) zu feucht
   - Frühling: (-3) zu trocken, (-2) ungünstig, (-1) neutral, (0) günstig, (1) zu feucht

4. Wie würden Sie die natürliche Tagesbeleuchtung im Büro bewerten? (Sonnenlicht...)
   - Lichtstärke: (zu dunkel) (-3) schlecht, (-2) rechtwinklig, (-1) neutral, (0) gut, (1) sehr gut
   - Grelles Licht (Computer Bildschirm): (sehr unangenehm) (-3) schlecht, (-2) rechtwinklig, (-1) neutral, (0) gut, (1) sehr gut
   - Steuerbarkeit: (unangenehm) (-3) schlecht, (-2) rechtwinklig, (-1) neutral, (0) gut, (1) sehr gut

5. Wie würden Sie die Beleuchtung im Büro bewerten? (Lampe, Neon Beleuchtung,...)
   - Lichtstärke: (zu dunkel) (-3) schlecht, (-2) rechtwinklig, (-1) neutral, (0) gut, (1) sehr gut
   - Grelles Licht (Computer screen): (unbefeindlich) (-3) schlecht, (-2) rechtwinklig, (-1) neutral, (0) gut, (1) sehr gut
   - Steuerbarkeit: (unbefeindlich) (-3) schlecht, (-2) rechtwinklig, (-1) neutral, (0) gut, (1) sehr gut

6. Wie würden Sie die Geräusche im Büro bewerten? (Hintergrunds-Geräusche)
   - Geräusche: (zu laut) (-3) sehr laut, (-2) rechtwinklig, (-1) neutral, (0) leise, (1) sehr leise

Bitte geben Sie Einflussfaktoren der Geräusche ein ____________________________

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7. Ist die Sicht auf eine Grünanlage, während Ihrer Arbeitszeit für Sie wichtig?

8. Wie würden Sie den Sicht-Zugang zu einer Grünanlage bewerten (Sicht auf einen Garten, Bäume)?

9. Ist der Innenbereich des Büros so gestaltet dass Sie gute Arbeit erstellen und Kreativ sind?

10. Wie würden Sie das Büromaterial bewerten (Sind Ihr Bürotisch, Stuhl, Tastatur und Monitor des Rechners auf ihre Höhe eingestellt)?

11. Wie fühlen Sie sich nach einem Arbeitstag?

12. Welche Änderungen würden Sie im Gebäude machen?

13. Wie alt sind Sie?

14. Geschlecht: weiblich / männlich

15. Durchschnitt der Arbeitsstunden pro Tag _______ Stunden

16. Berufsbezeichnung?

17. Bewerten Sie bitte Ihre Zufriedenheit?

18. Wie viele Tage benutzen Sie im Durchschnitt wegen Krankheit pro Jahr?

19. Würden Sie Insgesamt behaupten dass die Umgebung und die Struktur des Gebäudes Sie bei der Leistungsfähigkeit unterstützen?
CHAPTER 6
RESULTS AND CONCLUSION

Graphs and Charts

How would you rate the thermal comfort during these times of year?

![Temperature Commerzbank Chart]

Figure 6-1. Temperature rating of Commerzbank during all four reasons. Autumn and spring had the most neutral ratings of temperature, although many did report it was warm. Spring’s average temperature (0.53) rating was slightly warmer than autumn (0.27). Summer had the warmest average of 1.47. This could be because the clear glass and steel framing transmits heat very easily. During interviews, employees stated that the higher the floor, the warmer the temperature. Heat rising up from convection and the greater sun exposure could be reasons for this comment. Winter had the most varied results but no correlation could be found for this. Because many respondents did not fill in the location, it was difficult to predict if location influenced the response. It is possible that proximity to windows may cause some respondents to state if it was too cold being the winter gardens and exterior environment reach temperatures of 5°C. People who said it was too warm may have been closer to heat sources or simply have a higher metabolism. More low energy cooling systems should be looked at to compensate for the warm temperature ratings, such as ceiling fans.
How would you rate the thermal comfort during these times of year?

Figure 6-2. Temperature rating of Nord/LB during all four reasons. In summer and autumn, people tended to feel the temperature was too warm. Summer’s average rating was 1.68 and autumn’s was 0.56. Spring had the most neutral responses but an average of 0.52. Men tended to state the temperature was too warm while women felt both polar temperatures during winter and summer. The findings in winter could be a result of people sitting closer or farther from the window. People many times said the interior corridor would get too warm. Opening the windows helps regulate the office temperature but would cause the centralized heating system work more to compensate for the added cool air. More low energy cooling systems should be looked at to compensate for the warm temperature ratings, such as ceiling fans.
How would you rate the thermal comfort during these times of year?

![RWE Temperature Graph]

**Figure 6-3.** Temperature rating of RWE during all four reasons. Overall everyone was satisfied with the temperature of their office. Each employee can regulate their own office’s temperature to their needs with the climate surfboard. All season’s ratings were close to 0, except for summer with an average of 0.76.
How would you rate the humidity during these times of year?

Figure 6-4. Humidity rating of Commerzbank during all four reasons. Results for humidity were broad, although most people reported the humidity being neutral for all seasons, or slightly dry if they answered otherwise. The mean for winter had the lowest average rating of -0.97, -3 being the driest and 3 being the most humid. This is probably because the conventional fixed radiators at the side of the windows runs more for the cold climate, causing the air to be dry. Spring (average of -0.37) and autumn (average of -0.53) had the most neutral ratings. A humidifier in each office would help improve ratings.
How would you rate the humidity during these times of year?

Figure 6-5. Humidity rating of Nord/LB during all four reasons. Most people felt the humidity was neutral for all four seasons. Averages for all four seasons leaned more towards the dry rating. Autumn's average was -0.40, spring's was -0.44, summer's was -0.24, and winter's was -0.076. Few people who filled out the surveys commented they had never thought about the humidity of their workspace, until they thought about dry eyes and skin as a cause of dry air.
How would you rate the humidity during these times of year?

Figure 6-6. Humidity rating of RWE during all four reasons. While filling out humidity ratings, many people from Commerzbank and Nord/LB hesitated because they had never thought about it. The people in RWE, however, confidently circled neutral, meaning humidity was ideal.
How would you rate **natural day lighting** in your office space? (diffused light, sunlight, etc)

![Natural Light Levels chart](chart.png)

Figure 6-7. Natural daylight levels for all three buildings. Most ratings were neutral for all three buildings, meaning it wasn't too bright or too dark. Interestingly, occupants in Commerzbank who stated their office was too dark had their offices located by the atrium, towards the core. This is where many management positions are located. The average rating for Commerzbank was -0.12 (slightly dark) even with all the glazed interior walls. This could be because Commerzbank has the deepest floor plan compared to all three buildings so there is less light the farther you are from a window. Commerzbank also does not have glazing from the floor to ceiling like Nord/LB and the RWE Tower on the exterior. Nord/LB and RWE had about a fourth of respondents report the light levels were too bright. One man mentioned the conference rooms in RWE are completely closed off from natural daylight, causing people to want to leave the room.
How would you rate the controllability and glare of natural day lighting in your office space? (diffused light, sunlight, etc)

Figure 6-8. Controllability ratings and glare ratings from natural daylight for Commerzbank. The average rating for the ability to control daylight was 0.50, -3 being very unsatisfied and 3 being very satisfied. A wide spread of ratings were recorded. There was no correlation between office location and rating. The average rating for glare was 0.50. Exterior shading devices must help to control glare. Otherwise, all exterior sides of the building would get direct sunlight.
How would you rate the controllability and glare of natural day lighting in your office space? (diffused light, sunlight, etc)

![Natural Daylight Ratings for Nord LB](image)

**Figure 6-9.** Controllability ratings and glare ratings from natural daylight for Nord/LB. The average ratings were below neutral for the ability to control natural daylight (-0.24). Not all parts of the building use a double skin façade, so external blinds aren’t there. However, all offices to have a translucent screen can cover one half of the glazing. The building also automatically overrides the ability to lower the blinds if the wind is too high. Glare had an average rating of .20, slightly above neutral. A further look into the individual offices, especially the tower as they reported the lowest ratings, would be needed in order to understand what could be causing problem of glare. It may be because some windows do not come with exterior blinds and the interior screening devices cover only about 50% of the windows.
How would you rate the controllability and glare of natural day lighting in your office space? (diffused light, sunlight, etc)

![Natural Daylight Ratings for RWE](image)

**Figure 6-10.** Controllability ratings and glare ratings from natural daylight for RWE. Most people were satisfied with how they could control the natural daylight setting in the RWE Tower. The average rating was 0.88 even though most people answered satisfactory. This also correlated to the satisfactory ratings for glare in that building, though that average rating was 0.18.
How would you rate the artificial lighting (task lamps, ceiling lights, etc)?

Figure 6-11. Artificial light levels for all three buildings. For all three buildings, most people reported the light levels from artificial light fixtures to be neutral, neither too dark nor too bright. The average ratings for Commerzbank is 0.50, Nord/LB 0.08, RWE is 0.12.
How would rate the controllability and glare of **artificial lighting** (task lamps, ceiling lights, etc)?

![Artificial Light Ratings for Commerzbank](image)

Figure 6-12. Controllability ratings and glare ratings from artificial lighting for Commerzbank. The ratings for the ability to control the artificial lighting were widespread with an average of 0.07. In general, the ratings for glare were between neutral and satisfactory, with an average of 0.50. Occupants unsatisfied with the ability to control the fluorescent lights may not like that the system is automated to a prescribed light level.
How would rate the controllability and glare of **artificial lighting** (task lamps, ceiling lights, etc)?

Figure 6-13. Controllability ratings and glare ratings from artificial lighting for Nord/LB. The average rating for controllability of artificial lighting was -0.20 and the average rating of glare from artificial lighting was 0.48. It seems as though that each desk provides a task lamp, but it is not certain whether each office has the same kind of permanent light fixture on the ceiling. It seems like some have recessed fluorescent ceiling lights, while others have hanging fluorescent lights, or standing light fixtures.
How would rate the controllability and glare of artificial lighting (task lamps, ceiling lights, etc)?

![Artificial Light Ratings for RWE](image)

**Figure 6-14.** Controllability ratings and glare ratings from artificial lighting for RWE. Ratings for both are generally satisfactory. The average for controllability is 0.88 and the average for glare is 0.71. The high rating from glare could be a result of the offices’ involute down lighting lamps with fitted diffusers working well.
How would you rate the sound levels (background noise)?

![Sound Level Chart]

**Figure 6-15.** A) Sound level ratings for all three buildings. -3 being too loud and 3 being too quiet. B) Box Plot Chart of all building's sound rating.

Commerzbank had the noisiest sound level of all the buildings with an average rating of -1.33 (-3 being too loud). This is because the tower recently changed to a large open floor plan to fit as many as 30 people inside. People complained mostly of people talking on the phone as the source of noise and then technology (fax, phone, printers). One person mentioned there was no sound absorbing material. Another person said “8 people in the office on the phone” as a source of noise. The lack of conference rooms in each floor also contributes to this. For Nord/LB (average rating of -1.04), the most common cause of noise was from conversations being transmitted through the thin wall partitions. Others said people talking in the corridors and printers caused noise. From personal observation, Nord/LB workers appeared happy, open, and friendly towards one another. They always greeted each other while walking down the hallways. RWE had mostly neutral ratings (average -0.22) with some comments the source of noise was from the air conditioning and from open windows.
Is view to “green space” important to you while you are working?

Figure 6-16. Pie charts of responses for all three buildings. Commerzbank had the most respondents answer that view to green space was no important.

How would you rate your access to view green environments (view of gardens, trees, etc)?

Figure 6-17. Access to view green environments for all three buildings. Commerzbank had the highest average rating (1.40) of access to view green environments. This is not surprising being that one of the main design concepts for the building was the sky garden feature. RWE came in second (0.53) and Nord/LB came in third (0.04). A reason for the Nord/LB having the lowest ratings could be the interior of the building does not feature any trees, except for the one in the lobby and one in the courtyard. Even with the green roofs, the ratings were low. RWE may have earned satisfactory ratings because the tower has a view of the garden down below.
Is the office organized in a way that supports collaboration and creativity?

**Figure 6-18.** Building organized for collaboration and creativity ratings of all three buildings. Commerzbank had the highest average 0.77, Nord.LB the second highest average of 0.76, and RWE the third average of 0.35. Since Commerzbank is the only high rise utilizing the open floor plan and completely transparent partitions, the occupants may perceive this as a way to encourage collaboration and creativity. Nord/LB could also be perceived as being place for collaboration and creativity because of the transparent walls facing the corridors and spaces for informal meetings and conference rooms available. RWE surprisingly got some very satisfactory ratings, even it is the walls are opaque at eye level. One person reported office workers felt lonely while working here because there is no visual contact with other colleagues.
How would you rate the ergonomics of your workspace (desk, chair, keyboard and computer monitor adjusted to your needs)?

Figure 6-19. Ergonomic ratings for all three buildings. While interviewing an employee from Nord/LB, the researcher questioned if the company provided ergonomic work space. It was a question she had never thought of. From personal observations, it was clear the company did not provide simple needs such as monitor stand. However, because she had never thought headaches and back pains could be the result of a poor computer set up, she felt what she had was satisfactory. This helped lead to the conclusion that office workers who were knowledgeable about what made a work space ergonomic were actually unsatisfied with their work conditions provided by the company. Those who were satisfied were either not knowledgeable about the importance of practicing ergonomic set up or they simply never had an issue. The selection of furniture, desks, and chairs then becomes an important issue that must be solved during the design stage because to upgrade furniture in the future would be costly. One comment from a Commerzbank employee stated that adjustable tables and better chairs would improve the work conditions. Items such as monitor stands or wrist supports can be solved later.
How do you feel after work?” combined with “Age”

**Figure 6-20.** Plot of energy level vs. age for all three buildings. For energy levels, 3 is energized and -3 is tired. The question of how you feel after work (energized or tired) relates to the oxygen levels of the building. If the building has good ventilation, it is assumed people will feel more energized. Age also influences energy levels. No real correlation was found between age and how workers felt after work, except for in Commerzbank which also had the most responses. In Commerzbank, the younger the age, the more energized people felt. Nord/LB had the highest energy level ratings (average of 0.00) while Commerzbank had the lowest average of -0.77. The varied responses could be effected by hours worked, amount of sleep, metabolism, energy intake, stress, or the lack of responses.
Overall, do you think the building enhances productivity?

Figure 6-21. Productivity rating for all three buildings. Commerzbank reported to have the highest rating for productivity with an average of 1.07. Nord LB had an average of 0.84 and RWE had an average of 1.0.
Recommendations

As predicted, the selected case studies have neutral or satisfactory overall results in most categories. The major problems found were warm temperatures during summer for Nord/LB and Commerzbank, sound levels for offices sharing more than four people, and the ability for individuals to control the light levels.

When calculating the standard deviation of the responses, they were found to be high (between 1.5 and 2) most of the time, meaning responses had a wide spread. This could be a result of workers not taking the time to carefully read and think about the questions, because they were in a rush. Additional time to obtain more survey responses is needed to improve the accuracy of the results.

Based on the responses from the surveys, Commerzbank had the highest rating for providing a space that enhances productivity. The average score of Commerzbank was 1.07, meaning occupants agreed the building enhances productivity. This is surprising because it also had some of the lowest scores for thermal comfort and some workers commented that the natural ventilation is sparsely used because the windows are locked. It also had the lowest score for sound levels compared to the other two buildings. The high level of transparency and open floor plan in Commerzbank are speculations for these results. Though some researchers believe open floor plans and completely transparent partitions foster interaction, it is often the reason why it is too loud in the building. It can also result in visual distractions hampering people’s ability to focus.

Transparency/Opacity Ratio

The question of what kind of office enhances productivity the best then arises. Based on the results, a theory was made for what could be the ideal transparency
versus opacity ratios for the wall partitions of an office. An approximate calculation was made of the transparency versus opacity ratios for typical offices from all three buildings (See Figure 6-22). The calculation included the window view and all other walls enclosing a typical office. Though every company’s needs are different, the goal is to determine what could be the ideal ratio for every office. Every place ultimately must find their balance.

Commerzbank’s offices are nearly completely transparent with 96% of a typical office having transparent walls and 4% being opaque at the window where the radiators are. Nord/LB’s typical office with the built in storage furniture has 70% of its walls transparent and 30% opaque. RWE’s cellular-like offices are 20% transparent and 80% opaque. A slit of glazing occurs in the interior wall on the top of the door to allow natural daylight to enter deeper into the building. No visual and acoustical connection with colleagues is made in RWE except when the door is open towards the hallway. This limits the amount of approachable and informal communication amongst colleagues and does not support creative work. Complaints from inhabitants include feelings of loneliness.
Figure 6-22. Diagrams showing the transparent and opaque walls of each building’s typical office, along with their ratios. Commerzbank had the most transparency while RWE had the least.

Commerzbank’s interior transparency allows daylight to flow freely throughout the building and complete visual contact with colleagues. Proximity and visual contact also promotes more frequent interaction and relationship building, enabling them to share information, think creatively, and reach more innovative solutions. The interaction and openness is a trend that will become more popular in the future (Jaunzens 2). Though people may find the lack of privacy from transparent partitions to be distracting, as some of the case study occupants reported, it also acts as a self-monitor for office workers so they do not veer off task, such as surfing the internet. A good ratio to follow...
for transparency and opacity based on the results and research is a combination of Commerzbank’s and Nord/LB, which is approximately 90:10 (transparent: opaque).

**Noise Strategies**

Although Commerzbank was reported having the loudest sound level, the noise may have been an indication of communication and collaboration occurring. Is it possible that higher sound levels correlates to greater productivity? Most research, however, finds that excessive noise is a reason for lost productivity, such as colleagues not being able to understand one another. This was consistent with occupants who found high sounds levels to be undesirable. Guidelines for acceptable noise levels from the United States Occupational Safety and Health Administration should be used as minimum standards when designing spaces with different functions.

Spaces in need of high concentration should then be designed appropriately. Since normal windows easily transmit sound, glass partitions may not be desirable for quiet zones. Quiet zones, such as conference rooms and private spaces for added concentrations, should be designed carefully for acoustics. For this, consideration must be used when selecting wall partitions for offices. Wall partitions are rated with a Sound Transmission Class (STC). The STC is a single-number rating of a material's or an assembly's ability to resist sound transmission. The higher the STC, the more efficient the construction is for absorbing sound (Egan 179). The table in the next page shows minimum STC ratings for common walls between enclosed spaces in conventional office and conference areas.
Table 6-1. STC ratings for common walls between enclosed spaces in conventional office and conference areas (Source: Egan 334).

<table>
<thead>
<tr>
<th>Source Room</th>
<th>Conference Room</th>
<th>Private Office</th>
<th>Small Office</th>
<th>Open-plan office</th>
<th>Corridor</th>
<th>Background noise (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conference Room (w/ electrical amplification)</td>
<td>50</td>
<td>46</td>
<td>42</td>
<td>53</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>Conference Room</td>
<td>45</td>
<td>41</td>
<td>37</td>
<td>48</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Private Office</td>
<td>40</td>
<td>38</td>
<td>34</td>
<td>43</td>
<td>32</td>
<td>40</td>
</tr>
<tr>
<td>Small Office</td>
<td>37</td>
<td>34</td>
<td>31</td>
<td>36</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Open-plan office</td>
<td>48</td>
<td>43</td>
<td>38</td>
<td>-</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Corridor</td>
<td>50</td>
<td>47</td>
<td>43</td>
<td>-</td>
<td>-</td>
<td>55</td>
</tr>
</tbody>
</table>

Though expensive, a general recommendation is to use acoustical glass to divide office spaces with a rating of at least 48, even if it is a rating designed for conference rooms. This will prevent the distraction of hearing conversations from other rooms. One recommended wall assembly is the DeVac 640-AL model, a dual frame aluminum window. This removable panel with an acoustical liner has an STC rating of 48-54 for the window alone. This window can be used both in the exterior and interior of a building. Partitions like this will not absorb sound. Instead, these acoustical partitions are designed to block sound from another room emitting a sound source. The partition also will not block sound transmitted through the floors or ceiling. Ceilings and floors should have a high STC rating as well.
One office worker in Commerzbank commented that the “echo” was a source of noise in the room, and others suggested that sound absorbing materials would improve the acoustics of the office space. This is especially true for open floor plans with large volumes (Egan 61). To reduce reverberation, “the persistence of reflected sound energy” (Egan 62), sound absorbing materials could be applied as interior finishes. It would help eliminate noise sources the inhabitants reported, such as ringing telephones and conversations, printers, and faxes. When selecting materials for the floor, wall, and ceiling, one could select materials based on the absorption coefficient. The sound absorption coefficient, represented as $\alpha$ (sabins), is the effectiveness a material has to absorb sound. Theoretically, the coefficient can range from 0 (no sound energy absorbed) to 1.0 (complete sound energy absorbed) (Egan 42). For example, a floor finish of heavy carpet on foam rubber has a coefficient of .69 at 1000 Hz, whereas a
concrete floor has a coefficient of 0.02 at 1000 Hz (Egan 52). This means that the carpet will absorb 69% of the sound energy while the concrete floor will only absorb 2%. The carpet would be better to use as a floor finish than the concrete finish because it absorbs sound better. The finished materials selected should have a high sound absorption coefficient. Other materials such as fibrous ceiling boards, curtains, and carpets will also reduce sound levels (Egan 38). Breaking up the office into smaller sections will also cut back the reverberation time.

**Occupants per Office**

The trend in office work is moving from the routine to the creative. “Organisations are moving from individual based work (carried out in isolation) to cross disciplinary project team working for enhanced productivity. There is a general decentralisation of authority with a resulting increase in individual autonomy” (Jaunzens 2). With issues of noise complaints from other colleagues, the question then becomes what is the balance between sharing space with people so that collaboration is enforced and privacy is available to eliminate distractions. From the surveys, offices with as little as four people working reported noise complaints. With noise being one of the biggest distractions from work, it is advised that open floor plans should have no more than four people per space. But how big should the office be?

The Florida Building Code states that for every occupant in a business function, there must be at least 100 gross square feet of floor area (Florida Building Code TABLE 1004.1.1). This includes all spaces to be occupied. Imagine a cellular office having 10’x10’ of space; it would be too small. In addition, the RWE tower, estimated to have an area of 178 square feet per individual office, was said to be too small according to the occupants. The typical office in Nord/LB is approximately 215 square feet. One
person there stated that he/she would like more and bigger offices, while another
wanted less glass and more private space. From the occupant’s feedback, it is
estimated that a comfortable office should have 900 square feet of space with no more
than 4 people. Based on the feedback, the ideal ratio for a person per square feet could
be 1 person per 225 square feet.

The buildings surveyed could further improve their work spaces with renovations.
Since so many respondents complained about Commerzbank’s open floor plan, the
obvious suggestion is to decrease the number of people per office by creating offices
similar to Nord/LB’s, but with added personal space. A suggestion for the RWE tower is
to replace portions of interior partitions with glazing, especially in the conference rooms,
so that a ratio close to Nord/LB or Commerzbank is achieved. Another successful move
would be to do what Commerzbank did: create a flexible plan so that interior
renovations can be done easily as the company’s needs adjust.

Ideal Office

Based on personal observations, responses from inhabitants, and research, a
model for a productive office space was made (see figure 6-24). The model
demonstrates an office with working space for four workers, a transparency and opacity
partition ratio of 90:10, and a floor area of approximately 900 square feet. The partitions
of the desks are low so colleagues maintain visual connection to each other. A centrally
located table is provided for collaboration. The exterior window is completely
transparent to maximize daylight, although screening devices will always be necessary
to avoid glare.
Figure 6-24. Sketch of an ideal office based on results and research.

**Ideal Office Plan**

With the ideal office in mind, office buildings should include other spaces to meet the various functions needed in an office. Equally important are the collaboration spaces, such as open conference rooms or tables nearby for informal meetings. This supports why the club layout works best for all office types, since flexibility and options are important for productivity and collaboration.

The depth of a room also influences which type of offices can be made. According to Jaunzens, the building type with a floor depth of 15 meters ("medium depth") is good for all four types of office plans: hive, den, cell, and club. The other building types are the atrium building (with 15 meters of span), deep central core, and shallow depth. Commerzbank and Nord/LB have the atrium type which is still a desirable plan, while
RWE has the shallow depth, given it has a shallow ring of offices on the perimeter of the tower. The atrium types allows for “higher level of connectivity” (7). Deep core buildings are the least favored because they reduce the amount of natural daylight to enter the core of the building.

Each of the building case studies had distinct office layouts. The RWE Tower follows the Cell office plan with its divided offices on the edge of the buildings. This arrangement supports privacy and concentration. Nord/LB followed more the Den layout on the first six floors, although those floors featured characteristics of club layout with its informal meeting spaces, conference rooms, and kitchenettes. The tower of Nord/LB was clearly a club layout with each floor being unique and designed for special purposes. Commerzbank is a club layout, with a combination of cell and den work spaces. The plan balances work spaces with accessible gardens per every 4 floors, as well as one formal conference room per floor.

While each company will have its own needs and its distinctive work patterns, again the ideal office plan is the **club** layout. This is consistent with results from the surveys as Commerzbank was the highest rated office for providing a space for productivity. The club layout is a combination and variety of all these working patterns. The club layout provides high interaction and high autonomy so that workers may choose the balance between interaction and autonomy as needed. Based on this, the ideal office plan should feature the ideal typical office as designed in this thesis, plus open floor plans for hot desking and routine process work (Hive), private spaces to isolate noise, open tables, reserved and open conference rooms, and café and gardens for socializing. All these spaces combined will create a flexible and dynamic work
environment promoting creativity, collaboration, and productivity. Meanwhile, the architect should avoid a deep floor plan so daylight is permitted throughout the floor plan. Core functions, such as the elevators and fire stairwells, should also be placed outside like in Commerzbank and the RWE Towers so occupants are not divided. Team spaces meeting spaces should be centralized, while individual spaces should be adjacent to the window to ensure occupants have a view to the exterior.

**Conclusion**

While Commerzbank had the highest score for enhancing productivity, it also had the second highest score (1.21) when asked to rate job satisfaction, whereas RWE was first (1.80). Though their ratings could be influenced by the building, it could also mean the workers are simply happy with their scope of work and/or salary. Ironically, the average work day for the RWE employees was reported to be 10.63 hours, according to the survey (quite high).

Though this thesis focused on how employees self-rated the building, it ultimately does not measure their productivity. While there is no standard to measure productivity for every company, we do know the factors influencing it. Measuring productivity in a sustainable office versus a traditional one could itself be a topic of future research. A suggestion to all architects designing office buildings is to understand both the employees’ and company’s needs. Employee involvement should start in the beginning of any design phase to identify needs. Whether it is more individual controllability, additional individual and collaboration spaces, better environmental quality, or a view to a window, planning to fulfill their needs will be repaid in the long term with added productivity. It also is a way to attract and retain the best employees, as evidenced successfully with Google. Buildings should also be designed to conserve Earth’s
valuable resources. Since green buildings promote benefits such as better air quality and natural daylight, the overall ratings of these sustainable high rises buildings were generally satisfactory to the occupant’s needs and do enhance productivity. A good argument to convince clients to invest in productive work environments and sustainable buildings is the future savings on energy and productivity costs. The building case studies selected, though not perfect, exemplify of how architects can design buildings to save energy and provide a high standard of working space. Architects should learn from the mistakes of the past to improve the future of humanity and the environment.
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BIOGRAPHICAL SKETCH

Jennifer Mackey was born on March 10, 1985 in South Florida where she spent the majority of her childhood. She completed her post-secondary education at the University of Florida in 2007 with a Bachelors of Design in Architecture. After graduation, she took one year from school to gain work experience in Fort Lauderdale, FL. She also spent some time working for an architect in Milan, Italy.

In 2008, she returned to her studies at the University of Florida where she earned her Master of Architecture with a concentration in Sustainable Architecture. During her time at UF, she traveled to San Francisco as part of her design studio work to learn, first-hand, what a productive and creative work environment is. There she toured Googleplex, Intel, and IDEO and was inspired to apply these concepts into sustainable architecture.

Jennifer has had extensive international experience. During her undergraduate program, she studied abroad at the Vicenza Institute of Architecture for one semester. She spent personal time Europe for two summers where she learned basic French and became proficient in Italian. To expand her experience of Europe, she created a study aboard program at the Ecole Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. There, she took two courses taught in French, and one design studio which provided the opportunity to travel to Porto, Portugal for a class design project. She plans to use her international experiences and education to influence her sustainable architecture and planning designs.