DEVELOPING A PROTOTYPICAL BIOPHILIC LOCALIZED NATURAL AIRFLOW SIMULATOR (BLNAS) FOR A MODULAR WORKSTATION

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ABSTRACT

In recent years, architects have been increasingly focused on designing green, low-energy buildings that prioritize sustainability and energy efficiency. However, this emphasis on environmental considerations often overshadows the critical importance of creating indoor environments that promote occupants' well-being, comfort, and productivity. With people in industrialized countries spending nearly 90% of their time indoors, it is imperative to shift our attention to user-centric design.

This shift becomes even more significant when considering that office workers' salaries are about 100 times higher, per square foot than energy costs, underscoring the need to prioritize users. Indoor environments profoundly affect physical and psychological health, cognitive abilities, and productivity through factors like thermal conditions, lighting, air quality, and noise.

Furthermore, with over 60% of the world's population projected to inhabit urban environments by 2030, it is essential to address the potential negative impacts of living in crowded, enclosed spaces, particularly in light of experiences during the COVID-19 pandemic. This has brought the user experience into sharp focus, as isolation from nature and the outside world can have adverse effects.

In response, biophilic design principles, rooted in our innate connection with nature, have gained prominence. They aim to integrate natural elements into the built environment, enhancing user comfort and performance. Airflow is a vital element in biophilic design, contributing to healthy indoor environments. This research seeks to develop a prototypical biophilic localized system that simulates natural air features and attributes in indoor environments, to enhance occupants' health, wellness, and well-being.

By analyzing the available weather data sets, natural airflow features were determined. They were used to determine the most appropriate mechanical system and develop the settings to mimic the natural airflow patterns. The research ended up by determining the best scenarios for the developed biophilic system and put the base for future research that might evaluate the impact of the developed system on occupants' physiological and psychological aspects.

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GENERAL AUDIENCE ABSTRACT

Architects have long been focused on designing eco-friendly buildings, but there's a growing realization that focusing solely on energy efficiency isn't enough. Occupants spend the majority of their time indoors, and the quality of these indoor spaces profoundly impacts their well-being and productivity. Yet, often overlooked, are factors like lighting, air quality, and noise that can significantly affect how occupants feel and perform.

With rising urbanization and recent experiences during the COVID-19 pandemic highlighting the importance of indoor environments, there's a renewed emphasis on user-centric design. Biophilic design, which incorporates elements of nature into buildings, has emerged as a promising approach to enhancing occupants' health, wellness, and well-being. Airflow, a critical aspect of biophilic design, plays a key role in creating healthier indoor spaces.

This study aims to develop a prototype system that mimics natural airflow patterns indoors to promote occupants' health and well-being. By analyzing weather data, natural airflow features were identified and used to inform the design of a mechanical system. The goal is to create settings that replicate natural airflow patterns in indoor environments.

Ultimately, this research lays the groundwork for future studies to explore how such biophilic systems impact occupants' physiological and psychological health. By prioritizing user experience in building design, indoor spaces that not only conserve energy but also enhance the quality of life could be developed.

Dedication

I dedicate this dissertation to my royal family, whose unwavering support and boundless love have been the cornerstone of my academic journey.

To my king and queen

Dr. Oqlah Rabab'ah *and* ***Dr. Maysoon Al-Awaisheh***
for instilling in me the values of perseverance, dedication, and a thirst for knowledge. Your sacrifices and encouragement have paved the way for my success.

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This dissertation stands as a testament to the enduring bonds of family, and I am profoundly grateful for your presence in my life.

With all my love and gratitude,

Ikhlas O. Rabab'ah

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Table of Contents

DEDICATION ..... **I**

ACKNOWLEDGMENTS ..... **II**

TABLE OF CONTENTS ..... **IV**

LIST OF FIGURES ..... **VIII**

LIST OF TABLES ..... **XIII**

LIST OF ABBREVIATIONS ..... **XV**

1. CHAPTER ONE: INTRODUCTION **1**

1.1 OVERVIEW 1

1.2 PROBLEM STATEMENT 4

1.3 RESEARCH GOAL AND OBJECTIVES 5

1.4 RESEARCH METHODOLOGY 6

1.5 THEORETICAL FRAMEWORK AND EPISTEMOLOGY 8

1.5.1. Explanatory Research and Positivism *8*

1.5.2. Simulating Natural Airflow Patterns *8*

1.6 RESEARCH SIGNIFICANCE 9

1.7 RESEARCH LIMITATIONS 10

1.8 RESEARCH STRUCTURE 10

2. CHAPTER TWO: THEORETICAL BACKGROUND AND LITERATURE REVIEW 12

2.1. BIOPHILIA AND BIOPHILIC DESIGN 12

2.5.1. The Relationship Between Biophilia and Built Form *12*

2.5.2. Understanding Biophilia *13*

2.5.3. Theory of Biophilia *15*

2.5.4. Biophilia in Architecture *18*

2.5.5. Experience and Attributes of Biophilic Design *20*

2.5.6. Biophilic Design and the 14 Principles *23*

2.5.7. Benefits of Biophilic Design *27*
2.2. BIOPHILIA AND NATURAL VENTILATION 33
2.5.1. Properties of Natural Ventilation *33*
2.5.2. Benefits of Natural Ventilation *34*
2.5.3. Mechanism of Air Distribution *36*
2.5.4. Challenges of Using Natural Ventilation in Biophilic Designs *36*
2.3. VENTILATION AND THERMAL COMFORT 38
2.5.1. Thermal Comfort Parameters and Conditions for Human Occupancy *38*
2.4. CURRENT VENTILATION SYSTEM AND AIRFLOW IN ARCHITECTURE 42
2.5.1. Types and Properties of Mechanical Ventilation Systems *42*
2.5. PERSONALIZED VENTILATION 45
2.5.1. Benefits of Personalized Ventilation Unit *45*
2.5.2. Mechanism of Air Distribution *48*
2.6. SUMMARY 49

3. CHAPTER THREE: RESEARCH METHODOLOGY 50

3.1. INTRODUCTION 50
3.2. QUALITATIVE VS QUANTITATIVE 50
3.3. RESEARCH STRUCTURE AND PROCEDURE 52

4. CHAPTER FOUR: DATA COLLECTION 59

4.1. NATURAL AIRFLOW CHARACTERISTICS 59
4.1.1. Literature *59*
4.1.2. ASHRAE Standards *59*
4.2. DETERMINING THE LOCATION OF STUDY 61
4.2.1. Selection of Representative Locations *61*
4.2.2. Data Collection *64*
4.3. SUMMARY 71

5. CHAPTER FIVE: EXPERIMENT SPECIFICATIONS AND ASSUMPTIONS 73

5.1. MECHANICAL DEVICE SELECTION 73
5.1.1. Criteria for Evaluation *73*

5.1.1.1. Airflow Variability *73*
5.1.1.2. Turbulence Intensity (TI) *73*
5.1.1.3. Device Height *73*
5.1.2. Determination of Advantages *74*
5.1.2.1. Scoring System *74*
5.1.2.2. Importance Weighting *74*
5.1.2.3. Advantage Calculation *74*
5.1.3. Localized mechanical forced airflow system details *76*
5.2. RESEARCH WORKSTATION 77
5.3. RESEARCH WORK ENVIRONMENT 81
5.4. DATALOGGER 83
5.5. TSI AIR VELOCITY TRANSDUCER 87
5.6. EXPERIMENT SETUP AND DOCUMENTATION 89
5.6.1. Assembling the Workstation *90*
5.6.2. Configuring Datalogger with LoggerNet *91*
5.6.3. Powering the Datalogger and the Sensor *91*
5.6.4. Connecting the Datalogger with the TSI Air Velocity Transducer *92*
5.6.5. Sensor's Programming and LoggerNet Integration *93*
5.6.6. Setting Up the Sensor for Experimentation *95*
5.6.7. Setting Up the Sensor and the Mannequin (Test Dummy) *96*
5.7. CONCLUSION OF THE EXPERIMENTAL TEST SETUP 101
5.7.1. Research Variables *101*
5.7.2. Research Cases *104*
5.7.3. Diffusers Designs *106*
5.8. SUMMARY 109
6. CHAPTER SIX: DATA COLLECTION, RESULTS AND ANALYSIS 111
6.1. OVERVIEW OF DATA COLLECTION PROCESS 111
6.1.1. Experimental Setup and Iterative Development of the Prototype *111*
6.2. EXPERIMENTAL VARIABLES AND TEST CASES 113
6.2.1. Revised Variables and Test Cases *113*
6.3. DATA RECORDING AND RESULTS 114

6.3.1. 0 Degree Blade Angle *115*
6.3.2. 45 Degree Blade Angle *131*
6.4. DATA ANALYSIS AND EVALUATION OF THE CASES 144
6.4.1. Evaluation Factor: Natural Airflow Velocity Range *144*
6.4.2. Evaluation Factor: Minimum Correlation Coefficient *146*
6.4.3. Evaluation Factor: Airflow Velocity Fluctuations *155*
6.4.4. Evaluation Factor: Turbulence Intensity *160*
6.4.5. Evaluation Factor: Normal Distribution *165*
6.5. SUMMARY 168
7. CHAPTER SEVEN: PROPOSED DESIGNS AND CONCLUSION 170
7.1. PROPOSED DESIGNS 170
7.1.1. Vertically Oriented Mechanical Device Integration *170*
7.1.2. Horizontally Oriented Mechanical Device Integration *172*
7.2. CONCLUSION 174
7.2.1. Introduction *174*
7.2.2. Methodology *176*
7.2.3. Research Variables *177*
7.2.4. Results *178*
7.2.5. Research Contributions *179*
7.3. FUTURE RESEARCH 180
8. REFERENCES 187
9. APPENDIXES 207
9.1 APPENDIX A: THE FULL FILTERED HOURLY WEATHER DATA SETS FOR BLACKSBURG, VA AND LOS ANGELES, CA 207
9.2 APPENDIX B: THE FULL GENERATED DATA SETS FOR THE TARGET NATURAL CASE AND THE TWO BEST EXPERIMENTAL CASES 238

List of Figures

Figure 1: Research Structure (Illustrated by the Author). 11
Figure 2: Three Key Frameworks of Biophilic Design (Zhong et al., 2012). 27
Figure 3: Influence of Wind and Thermal Updraft on Ventilation (regel-air.com). 36
Figure 4: The acceptable range of operative temperature and humidity for spaces that meet the criteria specified in ASHRAE Standard 55 – 2017, Section 5.2.1.1 40
Figure 5: Main Research Stages (Illustrated by the Author). 51
Figure 6: Research Structure and Procedure (Illustrated by Author). 53
Figure 7: ASHRAE World Climate Zones Map (ASHRAE-2020). 62
Figure 8: ASHRAE North American Climate Zones Map (ASHRAE-2020). 63
Figure 9: Monthly Airflow Speeds (mph) for Blacksburg, Honolulu, and Los Angeles and the Natural Comfort Airflow Speed Range. 66
Figure 10: Normal Distribution of Blacksburg Hourly Airflow Velocity and the Natural Comfort Airflow Speed Range. 68
Figure 11: Blacksburg's Filtered Airflow Velocity Normal Distribution and the Natural Comfort Airflow Speed Range. 69
Figure 12: Blacksburg's Filtered Airflow Velocity Turbulence Intensity. 70
Figure 13: Vornado NGT42DC Energy Smart Tower Circulator with Options of 0 and 45-Degree Blades Angle. 76
Figure 14: Drawings for the 120° Straight Height-Adjustable Desk and (Steelcase.com) 79
Figure 15: Photos for the 120° Straight Height-Adjustable Desk (Steelcase.com) 80
Figure 16: Partial Plan of GFURR Office. 82
Figure 17: The Workstation and Experiment Location within GFURR Office. 83
Figure 18: CR1000X Front Angle View (campbellsci.com). 85
Figure 19: CR1000X Wiring Panel and Terminal Functions (campbellsci.com). 85
Figure 20: LoggerNet, Datalogger Support Software, Interface and Data Analysis (campbellsci.com). 87
Figure 21: TSI Air Velocity Transducer Model 8465 (tsi.com). 89
Figure 22: TSI Air Velocity Transducer Model 8465 Inside Enclosure (tsi.com). 89
Figure 23: The Process of Assembling the Workstation and the Final Result. 90
Figure 24: The Process of Configuration of the Datalogger with the LoggerNet Software. 91

Figure 25: Campbell Scientific CH100 Power Source Supply. 92
Figure 26: The Connections Created between the Datalogger CR1000X and the Sensor TSI 8465 93
Figure 27: The CRBasic Code utilized for programming the TSI Air Velocity Transducer Model 8465 94
Figure 28: TSI Air Velocity Transducer Programming and LoggerNet Integration. 95
Figure 29: The process of Setting Up the TSI Air Velocity Transducer. 96
Figure 30: The Mannequin Positioning 97
Figure 31: The Thermal Receptors Distribution on the Human Face 98
Figure 32: The Mannequin and Sensor Setup. 98
Figure 33: The Full Experiment Setup. 100
Figure 34: Illustration of Variables and Their Relationships for the Experimental Cases. 105
Figure 35: Visual Representation of the Horizontal Diffuser Designs with Vertical, Horizontal, and Circular Openings. 108
Figure 36: Visual Representation of the Vertical Diffuser Designs with Vertical, Horizontal, and Circular Openings. 109
Figure 37: Schematic Representation of the Tested Distances between the Mechanical Device and the Diffuser for a Vertical Mechanical Device Scenario. 112
Figure 38: Images of Selected Test Cases While Using Different Settings for the Mechanical Device and Different Diffusers. 113
Figure 39: Schematic Representation of the Vertical Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle. 116
Figure 40: Vertical Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle. 117
Figure 41: Recorded Data for the Vertically Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle. 118
Figure 42: The Process of Testing the Device's Best Upward Tilting Angle. 120
Figure 43: Schematic Representation of the Horizontal Mechanical Device with Direct Upward Airflow and 0-Degree Blade Angle. 121
Figure 44: Horizontal Mechanical Device with Upward Directed Airflow and 0-Degree Blade Angle. 122

Figure 45: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Upward Airflow and 0-Degree Blade Angle. 123
Figure 46: Schematic Representation of the Horizontal Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle. 124
Figure 47: Horizontally Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blades Angle. 125
Figure 48: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle. 126
Figure 49: The Process of Testing the Device's Best Downward Tilting Angle. 127
Figure 50: Schematic Representation of the Horizontal Mechanical Device with Direct Downeard Airflow and 0-Degree Blade Angle. 128
Figure 51: Horizontally Oriented Mechanical Device with Direct Downward Airflow and 0-Degree Blade Angle. 129
Figure 52: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Downward Airflow and 0-Degree Blade Angle. 130
Figure 53: Schematic Representation of the Vertical Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle. 132
Figure 54: Vertically Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle. 133
Figure 55: Recorded Data for the Vertically Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle. 134
Figure 56: Schematic Representation of the Horizontal Mechanical Device with Direct Upward Airflow and 45-Degree Blade Angle. 135
Figure 57: Horizontally Oriented Mechanical Device with Direct Upward Airflow and 45-Degree Blade Angle. 136
Figure 58: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Upward Airflow and a 45-Degree Blade Angle. 137
Figure 59: Schematic Representation of the Horizontal Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle. 138
Figure 60: Horizontally Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle. 139

Figure 61: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Forward Airflow and a 45-Degree Blade Angle. 140
Figure 62: Schematic Representation of the Horizontal Mechanical Device with Direct Downward Airflow and 45-Degree Blade Angle. 141
Figure 63: Horizontally Oriented Mechanical Device with Direct Downward Airflow and 45-Degree Blade Angle. 142
Figure 64: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Downward Airflow and a 45-Degree Blade Angle. 143
Figure 65: The Recorded Airflow Velocities for the 0-Degree Blade Angle Scenarios. 145
Figure 66: The Recorded Airflow Velocities for the 45-Degree Blade Angle Scenarios. 145
Figure 67: Airflow Velocities for Target Natural Case and the Two Experimental Cases 152
Figure 68: Blacksburg Natural Airflow Velocity Fluctuations. 156
Figure 69: Vertical Airflow Velocity Fluctuations. 157
Figure 70: Horizontal Airflow Velocity Fluctuations. 158
Figure 71: Overlaying the Natural, Vertical, and Horizontal Airflow Velocity Fluctuations. .. 159
Figure 72: Natural Airflow Turbulence Intensity. 161
Figure 73: Vertical Turbulence Intensity. 162
Figure 74: Horizontal Turbulence Intensity 163
Figure 75: Overlaying the Natural, Vertical, and Horizontal Airflow Velocity Turbulence Intensity 164
Figure 76: Filtered Airflow Velocity Normal Distribution from the Blacksburg Weather File and the Natural Comfort Airflow Speed Range. 166
Figure 77: Vertical Normal Distribution. 167
Figure 78: Horizontal Normal Distribution. 167
Figure 79: Overlaying the Natural, Vertical, and Horizontal Airflow Velocity Normal Distribution. 168
Figure 80: The Proposed Design for the Vertical Option. 171
Figure 81: The Specifications of the Proposed Design for the Vertical Option. 172
Figure 82: The Proposed Design for the Horizontal Option. 173
Figure 83: The Specifications of the Proposed Design for the Horizontal Option. 174
Figure 84: Current and Future Research Structure and Procedure. 184

Figure 85: Detailed Presentation for the Current and Future Research Methodology. 186

List of Tables

Table 1: Biophilic Patterns and Psychological Health and Well-being (Hung, S.H. and Chang, 2021). 30
Table 2: Biophilic Patterns and Physiological Health (Hung, S.H. and Chang, 2021)..... 32
Table 3: The Research Questions and Answering Procedure (Illustrated by the Author). 57
Table 4: The relationship between human comfort and airflow velocity (Pendwarden and Wise, 1975). 59
Table 5: Monthly Airflow Speeds in mph for Blacksburg, Honolulu, and Los Angeles (Climate Consultant). 65
Table 6: Sample of the Filtered Hourly weather data sets for Blacksburg and Los Angeles. 67
Table 7: Statistical Analysis for Blacksburg's Filtered Airflow Velocity (mph) Data Set. 68
Table 8: Statistical Analysis for Blacksburg's Filtered TI Data Set..... 69
Table 9: Scoring Process Based on the Specified Criteria for the Mechanical Devices..... 74
Table 10: Sample Comparison Between Different Types of Mechanical Devices (Amazon.com). 75
Table 11: The Scoring and Evaluation of the Alternative Mechanical Devices. 75
Table 12: Research Variables (Illustrated by the Author). 103
Table 13: Intersection Between Research Variables, and the Resulting Research Cases..... 104
Table 14: Revised Variables and Cases. 114
Table 15: Recorded Data for the Vertically Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle. 117
Table 16: Recorded Data for the Horizontally Oriented Mechanical Device with Upward Directed Airflow and 0-Degree Blades Angle. 122
Table 17: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle. 125
Table 18: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Downward Airflow and 0-Degree Blade Angle. 129
Table 19: Recorded Data for the Vertically Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle. 133
Table 20: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Upward Airflow and a 45-Degree Blade Angle. 136

Table 21: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle. 139
Table 22: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Downward Airflow and 45-Degree Blade Angle. 142
Table 23: ShortList of Natural Airflow Velocities, the Cases' Closest Speeds, and the Corresponding Speed Settings. 149
Table 24: Airflow Velocities for Target Natural Case and the Two Experimental Cases. 150
Table 25: A Sample of the Full Data Sets for the Target Natural Case and the Two Best Experimental Cases. 153
Table 26: The Calculated Minimum Correlation Coefficient for the Two Best Cases. 155
Table 27: The Proposed Research Questions and Answering Procedure. 182
Table 28: The Full Filtered Hourly Weather Data Sets for Blacksburg, VA and Los Angeles, CA. 207
Table 29: The Full Generated Data Sets for the Target Natural Case and the Two Best Experimental Cases. 238

List of Abbreviations

BLNAS	Biophilic Localized Natural Airflow Simulator
HVAC	Heating, Ventilation, and Air-Conditioning
CFD	Computational Fluid Dynamics
WHO	World Health Organization
SBS	Sick Building Syndrome
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
MRT	Mean Radiant Temperature
RA	System-Recirculated Air
FA	Fresh Air
COA	Conditioned Outdoor Air
MV	Mixing Ventilation
DCV	Diffuse Ceiling Ventilation
DV	Displacement Ventilation
UFAD	Under Floor Air Distribution
SV	Stratum Ventilation
IJV	Impinge Jet Ventilation
CJV	Confluent Jets Ventilation
WAV	Wall Attached Ventilation
IAJS	Intermittent Air Jet Strategy
POV	Protected Occupied Ventilation
PV	Personalized Ventilation
LEV	Local Exhaust Ventilation
LAF	Laminar Airflow
PiV	Piston Ventilation
SSI	Surgical Site Infections
TV	Total Volume Ventilation
ATD	Air Terminal Device
PE	Personal Exhaust
TMY	Typical Meteorological Year
GFURR	Global Forum for Urban and Regional Resilience
TI	Turbulence Intensity

1. Chapter One: Introduction

1.1 Overview

Architects have been designing low-energy, green buildings that meet LEED performance criteria, conserve the environment, and use fewer resources. Numerous studies and advancements have led to the commonality of such structures and systems. Buildings that are both extremely effective and efficient have been constructed with remarkable success by the design community. However, buildings should not be designed only for sustainability, and energy efficiency. According to Klepeis et al. (2001), people in developed nations spend about 90% of their time indoors. It makes sense to concentrate on these users, their comfort, productivity, and mental and physical well-being, and to design buildings and systems that support and improve these aspects. Additionally, from a financial standpoint and within the corporate sector, office worker salaries are roughly 100 times greater per square foot than energy expenditures (Yin et al., 2018). This implies that it can be worthwhile to prioritize the needs of the users over the building's efficiency. As such, developing indoor environments that are comfortable, healthy, and productive for users is essential.

Focusing on users is a problem that affects everyone. Both short- and long-term illnesses are impacted by interior design, extended work hours, and personal stress. Worker productivity declines and worries about sick building syndrome could be the first signs of this (Stansfeld and Candy, 2006; Wadsworth et al., 2010). The COVID-19 pandemic and the resulting societal shifts highlighted how critical it is to pay attention to indoor environment quality. The epidemic pushed designers and decision-makers to refocus their attention on the potential harm that indoor environments, which are isolated from outside environments, may bring to building occupants. Based on this isolation, Yin et al. (2018) have demonstrated the detrimental impacts on the occupants' physiological and psychological aspects.

Studies like Yin et al. (2018) have shown that indoor settings have an impact on people's productivity, health, and cognitive capacities. Numerous factors, such as temperature, interior

design, lighting, indoor air quality, noise, etc., contributed to this. Research from the United States suggests that by 2030, sixty percent of the world's population will reside in urban areas (Habitat, 2008). Accordingly, their settlement in crowded closed, and isolated environments may have a detrimental impact on their general well-being (Habitat, 2008). As a result, it is important to understand how to achieve this connection and how much it affects occupants to design buildings in a way that maximizes the user's connection to nature. Yin et al. (2018) suggested that implementing the concepts of biophilic design could be a useful strategy.

In literature, the merits of biophilic indoor environments have predominantly been elucidated through the lens of the biophilia hypothesis, as proposed by Wilson (1988). Wilson posited that humans possess an innate propensity to seek connections with the natural world (Wilson, 1988). Subsequent studies, such as the research conducted by Hartig and Kahn (2016), have underscored the profound impact of nature's connection on both physical and mental well-being. Their findings revealed that fostering a connection to nature positively influenced various aspects of occupants' health, including aiding in post-surgical recovery, mitigating stress, enhancing productivity, and reducing the prevalence of mental, cardiovascular, and mortality issues.

Consequently, there has been a surge in research aimed at enhancing indoor environments to promote vitality and well-being. Biophilic design has emerged as a pivotal approach in this endeavor, seeking to seamlessly integrate the built environment with nature to enhance user comfort and performance (Hartig and Kahn, 2016). By infusing indoor spaces with elements inspired by the natural world, biophilic design endeavors to create environments that not only nurture the human spirit but also optimize the holistic health of occupants.

Biophilic design in architecture hinges on integrating natural elements into constructed environments, fostering a symbiotic relationship between occupants and the natural world. Among the various techniques employed, as mentioned the incorporation of green interior walls stands out as a popular choice, offering both visual solace and enhancing indoor air quality (Yin and Spengler, 2019). Despite the evident benefits for users, implementing biophilic patterns encounters several hurdles, primarily stemming from the need to pinpoint features that positively impact occupants and devise effective metrics for their assessment. Nevertheless, the most

significant challenge lies in reconciling the demands of contemporary architecture with the imperative of establishing a profound connection with nature (Kellert and Finnegan, 2011). This necessitates a delicate balance between embracing modern design trends and addressing the inherent disconnection from nature, ensuring that biophilic principles remain integral to the evolution of architectural practice.

Biophilic design is an emerging trend in architecture and building design that strives to connect people with nature. This approach to design seeks to incorporate natural elements into the built environment to create a space that feels alive, vibrant, and welcoming. As part of this effort, the concept of "biophilic patterns" has been introduced, which focuses on 14 core elements that can be used to create a biophilic environment. These patterns include sunlight, natural materials, plants, views of nature, airflow, and more.

Airflow is an important element of these biophilic patterns. It is essential to provide a comfortable and healthy indoor environment. Natural ventilation is often used to improve airflow in buildings, but other techniques can be used as well. The airflow throughout a building can be managed to provide a more comfortable living environment by careful selection of windows, doors, and other features. To improve airflow in biophilic designs, natural ventilation is by no means the only solution.

Designers may explore alternative forms of airflow as part of their biophilic design approach, aiming to enhance indoor environmental quality. One strategy involves incorporating mechanical ventilation systems, which introduce fresh air while expelling stale air, thus ensuring a continuous circulation of clean air. Additionally, the integration of heat recovery systems can optimize energy usage by harnessing the heat from outgoing air to precondition incoming air, thereby reducing energy costs associated with heating or cooling. Complementing these systems, air filtration mechanisms serve to further purify indoor air by capturing particulates and pollutants, contributing to a healthier indoor environment. By integrating these technologies with natural ventilation strategies, designers can create synergistic airflow solutions that promote both sustainability and well-being within indoor spaces.

By integrating biophilic design principles, architects and designers can design spaces that not only promote health but also foster a sense of invitation and well-being. While airflow stands

as a crucial component within this framework, it's imperative not to limit considerations solely to natural ventilation. Rather, a comprehensive approach should encompass various forms of airflow to optimize indoor environments effectively. By amalgamating both natural and mechanical techniques, biophilic spaces can be curated to offer comfort, and health benefits, and facilitate human connection with nature.

With this objective in mind, this research endeavors to develop a system dedicated to simulating natural air movement within indoor environments, thereby enhancing biophilic features. This specialized system aims to replicate the nuanced dynamics of natural airflow, capturing its inherent variability and intricacies. By leveraging advanced techniques, this research seeks to create environments that not only mimic the refreshing qualities of natural air but also contribute to the overall well-being and engagement of occupants.

1.2 Problem Statement

Despite the numerous advantages of mechanical ventilation systems, their implementation can adversely affect the performance and health of building occupants by disconnecting them from nature and the outdoor environment (Yin and Spengler, 2019). Various studies have demonstrated that integrating biophilic principles into building design, such as incorporating elements of nature, can have positive effects on users (Stansfeld and Candy, 2006; Yin and Spengler, 2019). Natural ventilation, a key principle of biophilia (Sanchez et al., 2018), is increasingly being considered by designers to reconnect occupants with nature. However, there are several limitations to this approach:

1. Certain building types may not be conducive to natural ventilation.
2. Natural ventilation may not be suitable for all climate zones.
3. Natural Ventilation may not be appropriate during specific weather conditions or times of the day.
4. Natural ventilation tends to be intermittent.

If designers persist in implementing closed buildings with mechanical Heating, Ventilation, and Air-Conditioning (HVAC) systems, issues related to isolation from nature may continue to escalate in the future. Conversely, if architects and building owners opt to embrace

natural ventilation by opening buildings, they must address the aforementioned limitations. However, research is scarce on the efficacy of biophilic design techniques, particularly concerning natural ventilation (Sanchez et al., 2018).

One potential solution could involve redesigning common HVAC systems to emulate natural ventilation patterns while maintaining their current efficiency. Unfortunately, modifying HVAC systems like Variable Air Volume systems to mimic natural airflow patterns is highly complex and would necessitate access to functioning systems for reconfiguration and control adjustments. Therefore, this research proposes to design and develop a localized mechanical airflow system capable of simulating the variability of natural airflow. This system could be integrated into modular personal workstations as part of a strategy for creating biophilic work environments.

To address this objective, the research poses two primary questions:

1. What are the fundamental attributes and properties that define natural airflow patterns?
2. Is it possible to conceptualize, design, and develop a localized airflow system that accurately replicates the essential characteristics of natural airflow?

1.3 Research Goal and Objectives

This research aims to design and implement a prototype forced air system capable of mimicking natural airflow patterns within a modular workstation. This endeavor is aimed at improving the indoor environment by altering airflow dynamics, thereby fostering healthier and more comfortable indoor spaces. To achieve this goal, the study focused on developing a biophilic localized airflow system that replicates natural airflow, with the anticipation of positively impacting occupants. The research outlines the following objectives:

1. Conducting a comprehensive analysis of the attributes and properties of natural airflow by synthesizing information from relevant literature, established standards, and weather data records.

2. Enhancing the biophilic design paradigm by integrating a nature-inspired connection through the development of a localized airflow system that accurately emulates the characteristics of natural airflow.
3. Establishing and overseeing the implementation of a representative modular personal workstation equipped with the localized airflow system to gain insights into its practical application and effectiveness.

1.4 Research Methodology

This research project focuses on developing a biophilic localized airflow system designed to replicate natural airflow patterns within a modular workstation setting. To achieve this goal, the research was structured into four primary phases. The initial phase, comprising four key steps, is dedicated to the identification and comprehension of the fundamental attributes of natural airflow.

9.2 Determine the characteristics and features of natural airflow based on the literature and related standards.

9.2 Identify and collect the characteristics and features of natural airflow based on the available weather data files.

9.2 Organize and structure the data from steps 1 and 2.

9.2 Analyze the data in step 3 statistically.

Phase two is the experimental design and setup, and it consists of four main steps as follows;

2.1 Identify and determine the candidate airflow mechanism. Through this step, the optimum configuration and control strategy of a localized mechanical forced airflow system (prototype) was determined.

2.2 Identify candidate workstation.

2.3 Incorporate airflow mechanism into the modular workstation. This step took into consideration the outlet design and the airflow directions. For that, the industrial design process was used to consider the performance and appearance of the system and integrate it into the workstation.

2.4 Experimental design. This step focused on determining the research variables, determining everything related to the setup and prototype, and collecting and structuring the data. For this, the indigenous and exogenous variables associated with the experimental setup and development of the prototype were determined, the workstation and alternative localized airflow devices were set up, and the airflow at the location of a seated occupant was monitored and recorded.

Phase three is the data analysis, and it consists of one main step as follows;

3.1 The data from phase two were analyzed statistically. The results of this phase were used as feedback to phase two to develop and enhance the experiment and develop the prototype.

Phase four is the selection and design of the prototype, and it consists of one main step as follows;

4.1 The data from phase three were compared and analyzed. For this, statistical analysis was performed to compare the airflow characteristics at the location of the seated occupant with those of natural airflow from phase one. The setup with the highest correlation between the local measurements and the natural flow target was selected as the best prototype.

The researcher recognizes that there will be a need for at least two additional phases of the research that will be beyond the scope of the present study. In phase five, the interaction of the prototypical system with the mechanical system and its' forced air distribution will need to be determined. This would likely include the following two steps.

5.1 Determine the optimum air distribution of a mechanical forced airflow mechanism (prototype) by using Computational Fluid Dynamics (CFD) to test the integrated system from step 3 and the impact of the traditional HVAC system on the airflow patterns at the occupant location.

5.2 Determine the correlation between the resulting airflow patterns at the occupant's seated location to the desired natural airflow characteristics as determined in Phase 1 step 1.

In phase six, which is also beyond the scope of the current study, the performance of the prototype will be assessed. In this phase, the performance of the developed localized airflow system will be evaluated by measuring the physiological and psychological responses of occupants exposed to the prototypical system. It would consist of two main steps as follows;

6.1 Experimental approach; by evaluating the results with and without using the prototypical system.

6.2 Collecting the physiological and psychological responses and statistically analyzing them.

This research focuses on developing the prototype through phases one to four.

1.5 Theoretical Framework and Epistemology

1.5.1. Explanatory Research and Positivism

Explanatory research seeks to understand the causal relationships between variables by explaining why certain phenomena occur. It emphasizes the importance of empirical evidence and aims to uncover the underlying mechanisms driving observed phenomena. In the context of architectural design, explanatory research provides a systematic approach to understanding how specific design elements influence occupants' experiences and well-being.

Positivism, as a philosophical stance, emphasizes the objective and empirical investigation of phenomena. It asserts that knowledge can be gained through systematic observation, experimentation, and the application of scientific methods. In architectural research, positivism underscores the importance of rigorously testing hypotheses and theories through empirical data collection and analysis.

1.5.2. Simulating Natural Airflow Patterns

In the realm of architectural design, the ability to simulate natural airflow patterns is crucial for creating environments that promote occupants' health and well-being. Natural airflow plays a significant role in regulating indoor temperatures, air quality, and overall comfort levels and might

affect occupants' health and well-being. By simulating natural airflow patterns, occupant's health, wellness, and well-being could be enhanced.

The selected device for simulating natural airflow patterns is a pivotal tool in this process. Its ability to replicate natural airflow patterns within a built environment enables researchers to assess the effectiveness of design interventions in impacting occupants. Through detailed simulations and analysis, researchers can identify areas for improvement and refine design strategies to optimize occupants' comfort, health, and well-being.

For that, explanatory research and positivism, alongside the practical application of simulating natural airflow patterns, converge to underscore the importance of empirical evidence and systematic investigation in architectural design. Explanatory research provides a structured approach to understanding the causal relationships between design elements and occupants' experiences, emphasizing the role of empirical evidence in uncovering underlying mechanisms. Positivism reinforces this by advocating for objective and systematic observation, experimentation, and analysis to gain knowledge about architectural phenomena.

1.6 Research Significance

This research discusses important issues and major problems related to the negative impact of the current buildings on human health and well-being, the shortage of application and appropriate approaches to biophilic design, and the shortage of empirical studies demonstrating the efficacy of the biophilic design. Previous studies indicated that there are many problems facing occupants’ health and well-being inside the buildings, some of these studies indicated that the limited application of natural ventilation is among the most important of these problems. Based on this, the significance of this research includes:

1. Extend the approach of biophilic design to include natural air movement while overcoming the limits of natural ventilation.
2. Design and develop a prototypical localized airflow system applied to an office workstation.

3. Performance evaluation of the prototypical system to determine how closely the resulting airflow patterns at the location of a seated occupant correlate with the natural airflow patterns.

1.7 Research limitations

Ultimately, this research seeks to create indoor environments that are both healthier and more comfortable. This might be accomplished by creating a biophilic localized airflow system that mimics natural airflow, which might benefit the users. For that, all variables for this research are limited to the situation in Blacksburg, Virginia. The scope of the study is limited to the following:

1. Location: Blacksburg / Virginia.
2. Climate: Local climatic conditions in Blacksburg, Virginia.
3. Limits of the available data for analyzing the natural airflow patterns.
4. Type and characteristics of the mechanical airflow device and the control system.
5. Type and configuration for the modular personal workstation as provided by Steelcase.
6. Limits of the airflow monitoring equipment.

1.8 Research Structure

This research consists of seven main sections which include an introduction, literature review, research methodology, data collection, experiment specifications and assumptions, data collection, results and analysis, and proposed designs and conclusion. The introduction section mainly presents a holistic brief about the research problem, its goals, objectives, limitations, significance, methodology, theoretical foundation, and research structure. The literature review section was divided into six main parts covering the themes of this study and includes discussing biophilia and biophilic design, biophilia and natural ventilation, ventilation and thermal comfort, current ventilation system and airflow in architecture, personalized ventilation, and summary.

The third section is the research methodology. It was divided into parts that cover the research process; introduction, qualitative vs quantitative, and research structure and procedure.

The fourth section relates to data collection while the fifth section covers the experiment specifications and assumptions. The sixth section relates to data collection, results, and analysis. The seventh section covers the proposed designs and conclusion. It contains the proposed designs, conclusion, and suggestions for future studies. These sections were designed and structured to achieve the research goal and objectives. A mind map of the research structure is presented in Figure 1.

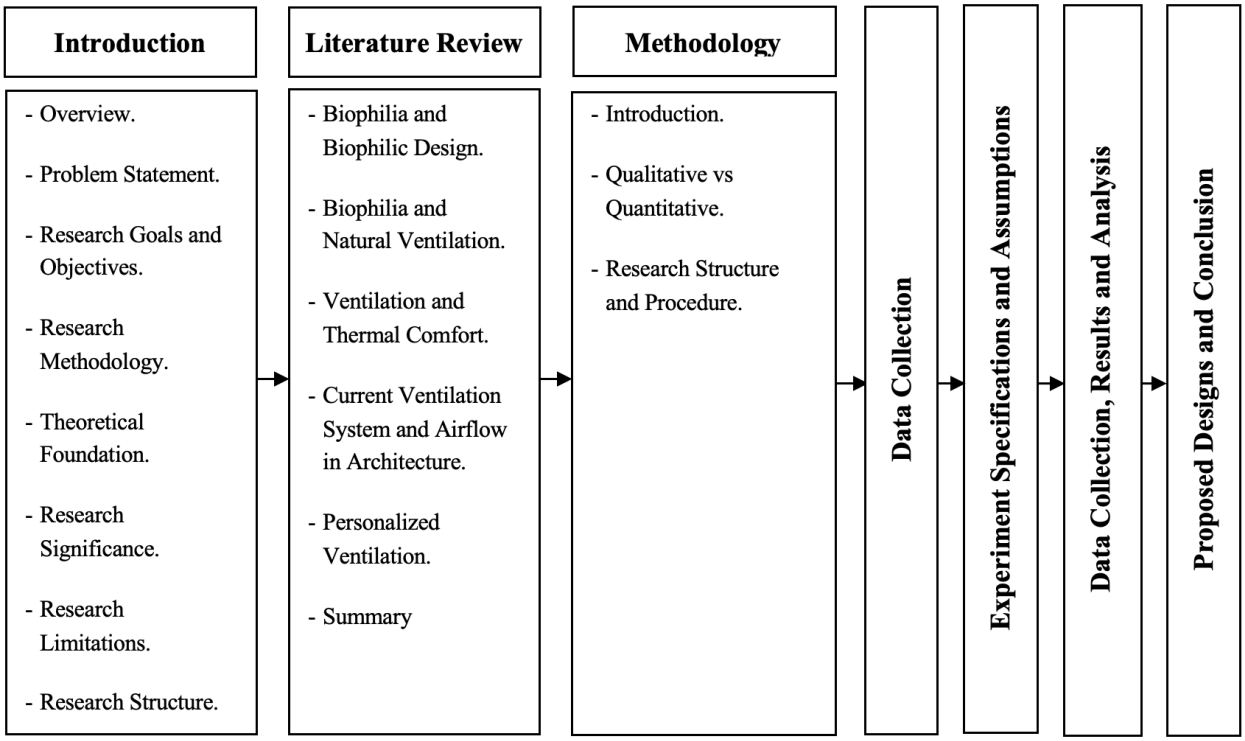

Figure 1: Research Structure (Illustrated by the Author).

2.Chapter Two: Theoretical Background and Literature Review

2.1. Biophilia and Biophilic Design

2.5.1. The Relationship Between Biophilia and Built Form

Nature and humanity are closely linked. The evolution of humans has always been significantly influenced by this interaction. Since the dawn of time, mankind has relied on nature for all of their survival needs, including food, clothing, shelter, and other basic necessities. The earliest humans had proximity to food and water supplies. They settled in naturally advantageous places where they could be protected from rivals and predators as well as the harsh weather. Large trees and caves are the oldest types of shelter. Later animal bones or tree branches were utilized to fashion an inverted V-shaped natural tent. A ring of stones or a dip in the ground was employed to firmly support that building. These rational building design principles, which mainly relied on nature, are among the earliest reliable forms of human habitation, which date back as far as 30,000 years.

Through the advancement of agriculture and trade, people became more formal and sophisticated in their living styles, which could be argued to be the beginning of architecture. As permanent settlements proliferated, sturdier buildings with straight walls made of clay, stone, wood, and sun-dried bricks started to appear. The majority of these prehistoric human communities were rural. Rural societies changed and became urban ones as the surplus of production started to arise, and cities started to develop. Around 3000 BC, the earliest cities began to emerge. In these cities, people were able to live together in vast communities and support one another. From trying to create habitats apart from the natural environment, this was the pivotal moment. One of the most important shifts over the ages was the urbanization of rural areas into huge cities. At the same time, humans began producing different metals and building materials like concrete. There was still some degree of dependence on nature while those materials were being made.

The need for buildings also increased as metropolitan regions' population densities rose during the 18th century. Huge constructions were the subject of engineering experiments. Although the buildings were formed of hefty stones and had strong, solid walls, the interiors were exceedingly dark and small. Successful experimentation with new materials like steel and glass during the "Industrial Revolution" gave rise to a whole new generation of extremely tall structures. The first high-rise structure to be supported by a steel skeleton of vertical columns and horizontal beams was the ten-story "Home Insurance Building" in Chicago. As a result of several technological advancements and social changes, the era of massive urban constructed forms like skyscrapers finally began in the 20th century (Landau and Condit, 1999). These buildings' ground-breaking construction methods ushered in a new era of huge steel and RCC skeletons that resembled glass boxes and flat, reflecting glass skins that had little to no connection to the natural environment. This surge in rapid construction was also not the best use of resources and energy because 40 to 45 percent of the world's energy and raw materials are used to construct buildings, and most crucially, their connection to the natural environment is frequently not thoroughly considered (Gottmann, 1966).

We rely on our surroundings to provide us with natural resources and to make it possible for us to form communities. Since humans are creatures of the earth, they react to its natural features, which can also be included in the built design rather than ignoring nature.

2.5.2. Understanding Biophilia

The American biologist and Harvard University professor Edward O. Wilson, winner of the Pulitzer Prize, was developing views on biophilia around the same time that the World Health Organization (WHO) developed Sick Building Syndrome (SBS). He defined Biophilia as “... the innate affiliation people seek with other organisms and especially the natural world.”

Throughout human evolution, we have relied on flora for food, fuel, and shelter. Being surrounded by plants and other natural components is essential to our basic life. Because of how deeply established this dependence is in human nature, biologists have given the irrational need to be around plants a name: biophilia. Wilson has also cited research that demonstrates that when given complete control over the setting of their homes and workplaces, people are drawn to locations that combine three key characteristics: being high up and overlooking the landscape,

being in an area with sparsely spaced-out trees, and being close to open water, such as lakes or streams.

To create healing or more naturalistic places, there have been numerous attempts to condense Wilson's beliefs into a set of design principles that may be applied to the built world. Many of them relate to the structure and architecture of buildings, making it challenging to incorporate them into already-existing structures, while others, like plants, are simple and inexpensive to do so.

Over the past few years, numerous studies have demonstrated the beneficial effects of green spaces on everyone's lives and the quality of work. A great example of "bringing a city into a garden" as opposed to "garden into a city" is Singapore's "Gardens by the Bay." The Super Tree Grove's vertical gardens span 101 hectares and are 25 meters high.

As the world population continues to urbanize, these attributes are ever more significant (Alcock et al., 2014; Barton and Pretty, 2010; Hartig et al., 2003; Hartig et al., 1991). Biophilic design can lower stress, anger, and anxiety, boost productivity and creativity, improve well-being, and hasten recovery. Views of nature are known to reduce sick-building syndrome, boost productivity, and enhance general health and well-being (Kellert, 2008).

2.1.2.1. Vegetation and Biophilia

Numerous scientific studies have demonstrated how plants may significantly improve human health and well-being, save energy costs, and boost productivity and profitability. Installing inside plants frequently reduces SBS complaints.

Generally, buildings and their occupants benefit greatly from the presence of plants; eliminating airborne volatile organic pollutants, decreasing the amount of CO_2, lessening ambiance noise, and cooling buildings. On the other hand, despite numerous benefits being quantifiable, no complete explanations have been identified; stress management, the rise in workplace productivity, and the decrease in complaints of SBS.

People may end up residing in areas with little green spaces as a result of rising urbanization. There is mounting evidence that living environments with more green space are positively correlated with self-reported measures of physical and mental health. Live plants show

off nature's tenacious resolve and purification process, which exchanges the surrounding air for new oxygen. As a result, a structure with vegetation purifies the air. In the summer, it naturally cools the structures, while in the winter, it makes them humid. To encourage a healthy lifestyle, the green skyscraper design theme is frequently adopted. According to studies, the amount of air dust in wooded areas might be up to 75% lower than in crowded, sparsely vegetated areas (Alcock et al., 2014).

Biophilia is not just related to plants, there are 14 other patterns of it but focusing on plants was the beginning of applying biophilia. One of the main areas of concentration for a building designer should be such study into the impact of other biophilia patterns. Also, their impact on the health of the building's occupants. It would be beneficial in many ways if researchers attempted to incorporate as many of the natural elements as possible into modern urban structures.

2.5.3. Theory of Biophilia

Biophilia, the innate human propensity to identify with nature, is still essential to people's physical and mental health and welfare in the modern environment (Wilson, 1986; Kellert and Wilson, 1993; Kellert, 2003; Kellert, 2012). The concept of biophilia comes from an understanding of human evolution, which shows that for more than 99% of the history of our species, biology has evolved in an adaptive response to natural factors rather than pressures imposed by humans. The majority of what we take for granted today is relatively new; large-scale food production dates back only 12,000 years; cities were created 6,000 years ago; mass production of products and services started 400 years ago; and electronic technology is only around a century old. Humans did not construct or create the bio-centric universe in which the human body, mind, and senses evolved.

The term "biophilia" was first coined in 1964 by German social psychologist and psychoanalyst Eric Fromm to refer to a psychological orientation of people who are drawn to life (Fromm, 1964). The phrase was later used by biologist Edward O. Wilson, who popularized it in his book "Biophilia" published in 1984.

2.1.3.1. Biophilia hypothesis proposed by Edward O. Wilson and Kellert

Biophilia translates to "love of life", where "bio" stands for life and "philia" stands for love. The description “a biological inclination to affiliate with natural systems and processes instrumental in their health and productivity” is used to describe biophilia.

Wilson claims that the term "biophilia" refers to "the connection that human beings subconsciously seek with the rest of life". He suggested that our biology may be what underlies people's strong ties to nature. Philias are the attractions and good feelings people have toward specific habitats, activities, and objects in their natural surroundings, as opposed to "phobias," which are people's aversions and fears of things in the natural world. The idea that human evolution occurred in natural settings and that early humans' dependency on and recurrent contact with natural components had an impact on their ability to survive is one of the main tenets of biophilia. The biophilia hypothesis essentially contends that modern people have an emotional affiliation with life and life-like processes and this affiliation is ingrained in our genetic structure.

According to the concept of biophilia, humans have a basic urge and predisposition to associate with other living things. It has been getting more and more support from several areas, particularly architecture. There are no known genes that affect biophilia, but it is believed that as humans have become more reliant on technology, our desire to connect with nature has diminished. According to Wilson and others, such losses in biophilia behavior could rob nature of its purpose, which would lead to a decline in human respect for the natural world. A potential element contributing to environmental damage and the high rate of species extinction has been identified as the decline in the human desire to engage with the natural world, which results in a decreased appreciation for the variety of life forms that support human survival. Therefore, re-establishing the human connection to nature has emerged as a key conservation subject.

According to one definition, biophilia is a "positive emotional attachment between humans and other living things. Innate refers to inherited traits that make up the core of human nature” and must be firmly distinguished from unfavorable or "bio phobic" reactions to natural things (Kellert and Wilson, 1993). When discussing biophilic design as a general term, one begins to examine the fundamental principles of how people interact with nature. The answer may lie in biophilic design, which links nature and the built environment to affect human behavior and well-being. The concept

of biophilia has been accepted by the design community's thinkers, who have coined the phrase "biophilic design" to describe how it might be applied to environmental design (Kaplan and Kaplan, 1982).

2.1.3.2. Biophilia hypothesis proven by Kaplan & Kaplan

The fields of philosophy and psychology are two that deal with the idea of biophilia. In psychology, it naturally and most significantly belongs to the field of evolutionary psychology. Some evolutionary psychologists have started to support Wilson's hypothesis that people have an innate preference for particular settings. While presumably the result of biological evolution, they have been improved via experience and civilization. The theory contributes to the explanation of why people protect important flora and flowers near their homes, as well as domestic and wild animals, even at the cost of their own lives. In other words, our inherent enjoyment of life contributes to its maintenance.

Researchers in the fields of psychology and sociology have consistently found that people, regardless of their age or cultural background, prefer the natural environment to build environments. They have also found that people have a preference for particular types of natural environments that have characteristics that are related to our ancestors' prehistoric instincts and habitats. The work of psychologists Stephen and Rachel Kaplan has shown that people almost universally prefer pristine natural settings to artificial or developed ones (Kaplan and Kaplan, 1982).

In the first experiment, participants were shown pictures of two different environments and asked to select their favorite. In a different study, participants were asked to report how various environmental photos made them feel (Kaplan and Kaplan, 1982). The study found that subjects favored photographs of a particular kind, specifically those of natural settings, particularly those with water features, elevated terrain, and sparse trees with tall canopies. In another experiment, subjects were given pictures of several artificial surroundings and asked to select their favorite. The study found that subjects consistently preferred photos that featured more natural components including water, plants, sunlight, and views of the outdoors (Kaplan and Kaplan, 1982).

2.5.4. Biophilia in Architecture

In the pursuit of creating spaces that resonate with the essence of human well-being, architects and designers have increasingly turned their attention to the concept of biophilia. In the context of architecture, this concept extends beyond mere aesthetics, representing a profound understanding of how integrating natural elements into the built environment can profoundly impact the psychological, and well-being of occupants. As our lives become more entwined with urban landscapes and technology, the importance of biophilic design emerges as a powerful treatment, offering an avenue to reconnect individuals with the vitality and tranquility found in the natural world. This exploration into biophilia in architecture delves into how nature can be seamlessly woven into the fabric of buildings, not only enhancing aesthetics but fundamentally transforming spaces into environments that nurture and inspire those who inhabit them. Theoretical studies argued about the impact of using the biophilic elements on occupants' psychological and well-being aspects. Below is a description of their findings.

2.1.4.1. Psychological factors

According to Modi and Parmar (2020), SBS is occasionally considered to be related to excessive work stress or discontent, dread of cramped quarters, poor interpersonal interactions, and poor communication. However, there are numerous instances of occupants exhibiting symptoms of SBS where none of the above causes could have been identified in the first place: the air quality is good, the temperature is comfortable, and the lighting is properly adjusted. In many cases, the removal or prevention of the aforementioned causes does not resolve the issue. Therefore, further action was still required to eradicate the disorders.

2.1.4.2. Occupant Well-Being in Architecture

The healing component is nature. Therefore, incorporating it into everyday life and design would encourage the creation of healthy living spaces. According to Alexander (2002), a person's life is influenced by their physical surroundings, and a building's shape can have an impact on a person's ability to love, well-being, and behavior. Environments and spaces have an impact on human well-being both overtly and covertly. Special gestures have an impact on one's body and mind. The horizontals are relaxing, and the vertical proportions lift us up. Spaces are intended to

invite you to stop or to allow you to move freely, depending on how they want to affect your state of mind (Alexander, 2002).

According to Day's definition in his book, health, and well-being are "a state of renewal, development, and balancing relation to the world," which explains the fundamental harmony of a man's physical environment's supply of water, air, and light (Day, 2002). Natural components that are necessary for human living, such as light, water, wind, plants, stones, etc., could be included while discussing human well-being within a certain region. These components can be used in the architectural constructed form to enhance occupant well-being (Modi and Parmar, 2020).

Clean air is getting harder to find. Traffic and industrial buildings damage the air outside, whereas off-gassing from furniture, building materials, and recycled air harms the air within. The built environment is where the majority of environmental dangers start. Poor urban settings can lead to headaches, eye strain, melancholy, stress, anxiety, and even cancer (Modi and Parmar, 2020). Through the natural cycles and processes that are inherent to all living things, including humans, natural materials have the potential to bring man closer to nature (Alexander, 2002). Local use of natural resources reduces industrial processing, lowers transportation emissions, and re-establishes human interaction with the environment (Modi and Parmar, 2020).

A healthy design approach leads to a healthier living environment. Buildings would become houses of the spirit if development took a more comprehensive, holistic approach and was guided by thoughts and feelings of wellness and vitality. With this mindset in mind, new buildings would be created, and existing ones would be altered to promote health and even healing (Day, 2002).

According to Modi and Parmar (2020), the health conditions associated with buildings are commonly classified as:

1. Sick Building Syndrome or Tight Building Syndrome.
2. A building-related disease is when the symptoms of diagnosable illness are identified and attributed directly to airborne building contaminants.
3. Building-associated symptoms.

When it comes to a building's environmental and psychological effects, people occasionally do not believe they might be the cause of illness. However, residents concur that physical elements like heating, ventilation, and organic volatile substances have a significant role in the psychological, organizational, and social effects (Baker, 1989). Architectural form's psychological and emotional consequences frequently take precedence over functional considerations. Spaces can be enjoyable by relaxing and stimulating the senses. The gratification of order, diversity, rhythm, and contrast through the senses is referred to as sensual delight. It can be accomplished through a revived space quality that uses color, texture, shape, and proportion. Through powerful impressions in space, visual sensation and movement in space produce happiness (Lynch, 1981).

It appears that unhealthy buildings have a long-lasting impact on tenants, who over time develop uncontrollable and irritating behavior patterns that hinder their productivity. In healthy and enjoyable environments, inhabitants are more likely to feel at ease. SBS is not just related to the building alone. In comparison to individuals who worked in buildings without the ill building syndrome, those who worked in SBS buildings were known to have significantly higher levels of resentment, distrust, defensiveness, anxiety, and confusion (Baker, 1989).

2.5.5. Experience and Attributes of Biophilic Design

There are three basic types of experiences of biophilic design:

1. Direct Experience of Nature
2. Indirect Experience of Nature
3. Experience of Space and Place

According to Wilson's approach to introducing biophilia into the human environment, "Direct Experience of Nature" is the most fundamental and successful of the three sorts of experiences. The other two are auxiliary and include artificial components. For biophilic design in the built environment, it would be most effective to choose any element of direct experience of nature (Lechner and Heating, 2009). The attributes of "Direct Experience of Nature," as described by Kellert and Finnegan (2011), are as follows:

2.1.5.1. Light

Natural light is essential to human health and well-being because it gives us the ability to recognize the day, night, and seasons in reaction to the sun's position and cycle. Being aware of natural light can improve comfort and happiness while facilitating movement and wayfinding. Through the imaginative interaction of light and shadow and the incorporation of light with spatial features, natural light can take on aesthetically pleasing shapes and patterns that go beyond mere exposure. Through the use of clerestories, glass walls, reflective materials, and other design elements, natural light may be introduced deeply into interior spaces. Through the contrast of lighter and darker areas and variations in daylight throughout time, one can feel light in motion.

2.1.5.2. Air

Human comfort and productivity are affected by natural ventilation. Variations in airflow, temperature, humidity, and barometric pressure can improve the sensation of natural ventilation in the built environment. These criteria can be met by providing access to the outside, either via straightforward methods like moveable windows or through more sophisticated technology and engineering methods.

2.1.5.3. Water

Water is necessary for life, and its beneficial presence in the built environment can reduce stress, foster satisfaction, and improve performance and health. When the five senses of sight, hearing, touch, taste, and movement are combined, the water attraction can be very strong. Different design techniques, such as views of notable water features, fountains, aquariums, built wetlands, and others, might satiate the craving for touch with water. Water in the built environment is frequently most appealing when it is clean, in motion, and experienced via numerous senses.

2.1.5.4. Vegetation

One of the best methods for integrating a sense of nature into the constructed environment is the use of vegetation. The presence of plants can improve comfort, physical health, performance, and productivity while reducing stress. The vegetation around constructed landscapes and

buildings ought to be dense, ecologically integrated, and inclined to favor native species over invasive and exotic ones.

2.1.5.5. Weather

People's experiences of nature have always included knowledge of and responsiveness to the weather, which has been crucial to human fitness and survival. In the built environment, the experience of weather perception can be both enjoyable and stimulating. Direct exposure to outdoor conditions as well as the creation of weather-like conditions by adjusting airflow, temperature, barometric pressure, and humidity can both cause this. Views of the outside, movable windows, porches, decks, balconies, colonnades, pavilions, gardens, and more are examples of design strategies.

2.1.5.6. Animals

Throughout human history, non-human animals have played a significant role in people's experiences. However, it can be difficult to integrate it into the built environment. Through such design techniques as feeders, green roofs, gardens, aquaria, aviaries, etc., one can come into contact with animal life. Contact with animals that are isolated and infrequent generally has minimal effect. Contact with animal life should, whenever possible, involve a variety of species and emphasize native rather than exotic animals.

2.1.5.7. Natural Landscape and Ecosystems

Plants, animals, water, soils, rocks, and geological formations are all interrelated in natural landscapes and ecosystems. People tend to favor landscapes with qualities vital to human evolution, such as wide-spreading trees, an open understory, the availability of water, forested margins, and other elements. In the built environment, self-sustaining ecosystems can be created using many architectural techniques, including artificial wetlands, grassy glades and forests, green roofs, and artificial aquatic environments. Views, observational platforms, direct engagement, and even active participation can encourage contact with natural systems.

2.1.5.8. Fire

The ability to regulate fire, which enabled the harnessing of energy beyond that of animal life and promoted the transformation of objects from one condition to another, is one of humanity's greatest achievements. Both comfort and worry can be felt being around the fire. Construction of fireplaces and hearths can create the gratifying presence of fire in the built environment (especially in cold areas), but it can also be creatively reproduced with the use of light, color, movement, and materials with different heat conductance.

2.5.6. Biophilic Design and the 14 Principles

Variables in biophilic architecture were first defined by Heerwagen and Hase (2001). Based on habitability, natural elements, process, design geometry, joy, and enticement, they assigned different natural qualities to eight criteria. Despite being a first effort, their framework showed how "natural" could be conceptualized differently in design. A few years later, the book Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life was co-authored by a group of proponents of the biophilic movement (Kellert, 2008). With two fundamental dimensions, six elements, and more than seventy contributions, Kellert (2008) offered a more methodical explanation of biophilic design in this volume.

To design biophilic buildings, Heerwagen and Gregory (2008) presented various perceivable and cognizable qualities or traits of "natural" settings. Additionally, Cramer and Browning (2008) provided three draft categories for biophilic structures. Terrapin Bright Green, a building consulting company, identified fourteen biophilic design patterns based on these three criteria (Browning et al., 2014). Similarly, Kellert and Calabrese (2015) condensed Kellert's (2008) original framework and suggested a new one that contains twenty-four traits divided into three categories. Later, the proponents of these two related frameworks improved and updated them (Browning and Ryan, 2020; Kellert, 2018). Recent research by Xue et al. (2019) suggested links between "environment" and human health and well-being, both from an individual and social (public health) standpoint.

In this literature review, three sample conceptual frameworks among the many biophilic design interpretations were selected to undertake a comparative analysis (Browning and Ryan,

2020; Kellert, 2008b, 2018) and presented in Figure 2. In certain significant architectural certificates, these three frameworks are frequently employed as the conceptual foundation for establishing standards about natural interaction and connection (e.g. LBC, WELL, and LEED). Many more researchers have also used them to examine biophilic design (Abdelaal and Soebarto, 2019, Aye et al., 2019, Gillis and Gatersleben, 2015, Park and Lee, 2019, Peters and D'Penna, 2020). Few studies, however, have analyzed whether the terminologies are acceptable to express "nature" in architecture more explicitly instead of adding to the ambiguity and discussing the taxonomies of "nature" in these frameworks.

The three frameworks all have the same general goal - to aid designers in comprehending and putting the idea of biophilic design into practice - but they also serve different purposes. The interpretations of Kellert (2008, 2018) are based on the biophilia theory and biophilia values taken from evolutionary psychology. In contrast, Browning and Ryan (2020) look at how biological reactions, psychological, and physiological health, and cognitive performance relate to human-nature relationships (Browning et al., 2014). Additionally, Kellert's (2008) first framework is presented as a thorough specification of biophilic design, in which inclusion is praised. This demonstrates the developer's desire to use this idea as an all-encompassing explanation for comprehending "nature" in design. In the most recent frameworks, however, the emphasis has shifted away from the older exhaustive enumeration and toward a model that is clearer and easier to understand. It is shown in two ways: first, by the framework structure (categorizations) that was used, and second, by the elements that were included and categorized.

Key proponents recently agreed on categorizing explanations in relatively brief ways. In the beginning, Kellert (2008) used a hierarchical structure in his framework, moving from the fundamental distinction (dimensions) to subdivisions (components and characteristics). "Organic or naturalistic" dimensions are those that directly, indirectly, or symbolically resemble "natural" forms, whereas "place-based or vernacular" dimensions are those that are culturally or environmentally linked to specific places (Kellert, 2008). However, this hierarchical taxonomy occasionally leads to ambiguity because Kellert did not elaborate on the relationship between the fundamental two "dimensions" and the subsequently classed "components" and "attributes." By combining previously split "dimensions" and "elements" into three "experiences", he changed the three-level taxonomy to a two-level structure (Kellert, 2018):

1. "Direct experience of nature," which refers to "contact with basic features and characteristics of the natural environment".
2. "Indirect experience of nature," which refers to "converting empirical and objective reality into symbolic and metaphorical forms through projecting thoughts, images, and feelings,".
3. "Experience of space and place," which refers to "the spatial setting," to "consider how people manage and organize their environmental circumstances".

Similar to this, Browning and Ryan (2020) grouped different aspects of nature - physical, metaphorical/representational, and emotional - into three categories: "nature in the space," "natural analogies," and "nature of the space."

Nevertheless, the two most current frameworks still contain certain ambiguities. In terms of how it connects to touch with nature, Kellert's (2018) "sense of space and location" is difficult to comprehend. This kind comprises a variety of natural spatial features that have been labeled as "sensory aesthetic" or "survival-advantageous" (Heerwagen and Gregory, 2008; Hildebrand, 2008), in addition to the Place Attachment Theory criterion for a sense of belonging (Manzo, 2003). Instead of just experiencing the common areas and places, producing these impacts (pleasant experiences) requires specific arrangements. Therefore, a clearer expression is required. Two of the three patterns listed under the category of "natural parallels" in Browning and Ryan's (2020) framework can also be categorized into the other two categories. A physical form of "nature in the space" is a "material link with nature," while a quality or feature of "nature of the space" is "complexity and order."

Kellert (2008, 2018) typically categorizes heterogeneous nature into various categories based on qualities (concrete, simulated, emotional, or others), referring to them as "attributes." By applying a "pattern" language taken from an architectural theory book, A Pattern Language (Alexander et al., 1977), Browning and Ryan (2020) elaborate on the functional importance of nature in architectural design. Even though different authors use different terminology, several common aspects are present. For instance, "light," "air," and "water" are similar to "dynamic and diffuse light," "thermal and airflow variability," and "presence of water"; "weather," "changes, ages, and the patina of time," are "connection with natural systems,"; "natural shapes and forms," and "natural geometrics," are suggested as "biomorphic forms and patterns"; and “natural materials" suggested as "material connection with nature". They also concur that nature can be

psychologically experienced through intentional spatial arrangements, such as creating a "prospect," "refuge," "complexity and order," or "ordered complex" (Browning and Ryan, 2020; Kellert, 2018).

Divergences can also be seen in the particular points made by various authors. Because love for "living organisms" is at the heart of biophilia theory, Kellert (2018) proposes "animals" and "plants" as two fundamental aspects separately. He also includes "fire" because it is seen to be crucial to human life. A distinctive pattern, "non-rhythmic sensory stimuli," is defined in Browning and Ryan's (2020) framework as the " stochastic and ephemeral connection with nature that may be analyzed statistically but may not be predicted precisely". Additionally, they contain the feelings associated with certain settings, such as "mystery," "risk/peril," and one specific pattern called "awe," which is defined as "stimuli including other biophilic patterns that defy an existing frame of reference and lead to a change in perception" (Browning and Ryan, 2020).

Previous frameworks complement, confirm, correct, or improve one another. But there are a few issues, though, that could make this interpretation difficult to understand. The first is that the dichotomous expression results in overlaps between the elements. According to Browning and Ryan (2020), the 15 patterns are divided into two categories; "visual connection with nature" and "non-visual connection with nature," with the other 13 patterns being broadly covered by either category. Additionally, repeats may be seen in Kellert's (2008, 2018) classifications, such as the overlap between "information richness" and those that depict complex forms and "sensory variety" and those that give multi-sensory experiences (such as water, plants, and weather) (e.g. natural geometries and organized complexity). Additionally, only practices that have "positive environmental impacts" and improve "people's physical and mental health, productivity, and wellbeing" fall within the criteria of "biophilic design," according to the original definition (Kellert, 2008). To reduce the risk of fire, modern architecture frequently depicts "fire" in metaphorical or symbolic ways, especially in high-rise buildings. 'Non-rhythmic sensory stimuli' frequently come with the worry of evoking erratic psychological reactions and diversion. Because of this, these components do not adhere to the principles of biophilic design. According to Zhong et al., (2021), Figure 2 presents a comparison between the main three frameworks of biophilic design.

2 Dimensions, 6 Elements, and 72 Attributes of Biophilic Design (Kellert, 2008b)					
I. Organic or Naturalistic				**II. Place-based or Vernacular**	
1. Environmental features	**2. Natural shapes and forms**	**3. Natural patterns and processes**	**4. Light and space**	**5. Place-based relationships**	**6. Evolved human-nature relationships**
• Color • Water • Air • Sunlight • Plants • Animals • Natural materials • Views and vistas • Façade greening • Geology and landscape • Habitats and ecosystems • Fire	• Botanical motifs • Tree and columnar supports • Animal (mainly vertebrate) motifs • Shells and spirals • Egg, oval, and tubular forms • Arches, vaults, domes • Shapes resisting straight lines and right angles • Simulation of natural features • Biomorphy • Geomorphology • Biomimicry	• Sensory variability • Information richness • Age, change, and the patina of time • Growth and efflorescence • Central focal point • Patterned wholes • Bounded spaces • Transitional spaces • Linked series and chains • Integration of parts to wholes • Complementary contrasts • Dynamic balance and tension • Fractals • Hierarchically organized ratios and scales	• Natural light • Filtered and diffused light • Light and shadow • Reflected light • Light pools • Warm light • Light as shape and form • Spaciousness • Spatial variability • Space as shape and form • Spatial harmony • Inside-outside spaces	• Geographic connection to place • Historic connection to place • Ecological connection to place • Cultural connection to place • Indigenous materials • Landscape orientation • Landscape features that define building form • Landscape ecology • Integration of culture and ecology • Spirit of place • Avoiding placelessness	• Prospect and refuge • Order and complexity • Curiosity and enticement • Change and metamorphosis • Security and protection • Mastery and control • Affection and attachment • Attraction and beauty • Exploration and discovery • Information and cognition • Fear and awe • Reverence and spirituality

3 Experiences and 25 Attributes of Biophilic Design (Kellert, 2018)		
1. Direct Experience of Nature	**2. Indirect Experience of Nature**	**3. Experience of Space and Place**
• Light • Air • Water • Plants • Animals • Landscapes • Weather • Views • Fire	• Images • Materials • Texture • Color • Shapes and forms • Information richness • Change, age and the patina of time • Natural geometries • Simulated natural light and air • Biomimicry	• Prospect and refuge • Organized complexity • Mobility • Transitional spaces • Place • Integrating parts to create wholes

3 Categories and 15 Patterns of Biophilic Design (Browning and Ryan, 2020)		
1. Nature in the Space	**2. Natural Analogues**	**3. Nature of the Space**
• Visual Connection with Nature • Non-Visual Connection with Nature • Non-Rhythmic Sensory Stimuli • Thermal & Airflow Variability • Presence of Water • Dynamic & Diffuse Light • Connection with Natural Systems	• Biomorphic Forms & Patterns • Material Connection with Nature • Complexity & Order	• Prospect • Refuge • Mystery • Risk/Peril • Awe

Figure 2: Three Key Frameworks of Biophilic Design (Zhong et al., 2012).

2.5.7. Benefits of Biophilic Design

According to White et al. (2019), spending 120 minutes in nature each week improves one's health and well-being. In general, people believe that parks and other green spaces are essential for their physical and mental well-being, particularly if they have features like paths, trees, seating, shade, and water (Lopez et al., 2020). Therefore, spending time in nature may be considered a resource for solving health issues and supporting the human ecological system, which boosts several advantages for both physical and mental health.

Since humans are a part of the biosphere and an ecosystem, it is not surprising that they have strong emotional ties to the natural world. People love savanna-like environments and have

optimistic outlooks that encourage them to spend time in nature (Balling and Falk, 1982; Heerwagen et al., 1993). Wilson (1984) argued in the Biophilia Hypothesis that people have a strong bond with the natural world and other living things. According to Joye and De Block (2011), distinct genetic dispositions affect a person's propensity for biophilia. The benefits of nature versus urban areas for restoring attention, experiencing good feelings, reducing stress, and other physical benefits have been the subject of several environmental psychology studies (Berto, 2005; Barton and Pretty, 2010; Hartig et al., 1991; Kaplan and Kaplan, 1989; Ulrich, 1983; Kim et al, 2016; Marcus and Sachs, 2013; White et al, 2019). To strengthen people's ties to nature and promote health, Kellert (2018) highlighted human adaptations and design applications that emphasize the usage of biophilic design elements (Browning et al., 2014; Berto et al., 2015). To give people the health advantages of much-needed exposure to nature, these designs, which are inspired by natural patterns, qualities, and elements, encourage the implementation of these features and systems in constructed environments.

Although there is a wealth of research discussing how biophilia and biophilic architecture relate to human health, a comprehensive examination of the connection between nature and health is still absent. The advantages of biophilic design were gathered from the literature to support this study and divided into two primary categories: the psychological and well-being benefits, and physiological benefits.

2.1.7.1. Biophilic Patterns and Psychological Health and Well-Being

Table 1 lists the favorable effects of biophilic designs on psychological health and well-being, including but not limited to sensations of good emotions and pleasure, attention restoration, preference, feelings of relaxation, and a reduction in aggression, among other things. Additionally, it involves enhancing cognitive performance and functionality.

Several studies found that visual and non-visual connections to nature and direct experiences with nature that are made possible by the presence of plants have a positive effect on psychological health and well-being in outdoor environments and interior designs (Barton and Pretty, 2010; Hartig et al., 2003; Larsen et al., 1998; Orsega-Smith et al., 2004; Pheasant et al., 2010; Thomsen et al., 2011). Those results are in line with two environmental psychological theories; the Attention Restoration Theory (Kaplan and Kaplan, 1989) and the Stress Reduction

Theory (Ulrich et al., 1991), which explain two ways in which contact with nature improves people's psychological states. The presence of plants in an office also reduces perceived stress (Dijkstra et al., 2008; Larsen et al., 1998). Furthermore, Zadeh et al. (2014) found that hospital and office workers who have window views of nature and sunlight perform better and feel happier, and patients heal more quickly after surgery. In addition, a lot of the literature discussed how "direct experience with nature," or having plants in both an indoor and outdoor setting, can enhance cognitive functions and performance by enhancing communication, concentration, and productivity (Shoemaker et al., 1992; Thomsen et al., 2011; Larsen et al., 1998; Zadeh et al., 2014). According to one of the research referenced, being physically surrounded by nature not only enhances sensory perceptions and feelings of well-being but also changes states of consciousness, particularly relaxation feelings (Kjellgren and Buhrkall, 2010).

However, there were few conclusions drawn regarding the psychological benefits of indirect encounters with nature, such as biomorphic shapes and patterns, objects, and natural pictures, which may increase creativity and productivity (Joye, 2007; Lichtenfeld et al., 2012). Schatz and Bowers (2005) looked into the effects of color design on employee moods, productivity, and satisfaction. In a study that used natural elements in a hospital setting, Tsunetsugu et al. (2007) found that an interior that contains 45% wood creates a feeling of coziness, naturalness, and restfulness (Nyrud et al., 2014).

The definition of "Space and Place" is the character of the space. Exposure to natural habitats with low prospect levels and high refuge levels isn't as restorative as exposure to those with high prospect levels and low refuge levels, but it may raise negative feelings, physical stress, and attention fatigue (Gatersleben and Andrews, 2013). The feeling of being in tune with nature in a naturally designed setting, as opposed to an urban setting, has been demonstrated to significantly improve psychological health and well-being by affecting pleasure and emotion, restoring attention, and reducing stress (Browning et al., 2014; Hartig et al., 2003; Ryan et al., 2014; White et al., 2010). Additionally, a natural-setting space can evoke a sense of mystery, attraction, and oneness (Herzog and Bryce, 2007; Herzog and Kropscott, 2004). Rapee (1997) discovered, however, that perceived risks during outdoor activities, such as scuba diving, hiking, or being in a forest or alley might cause anxiety and terror.

According to Hung, S.H., and Chang (2021), Table 1 presents the biophilic patterns and their impact on psychological health and well-being.

Table 1: Biophilic Patterns and Psychological Health and Well-being (Hung, S.H. and Chang, 2021).

	Direct experience of nature					Indirect experience of nature				Space and place			
	Visual connection to nature (Barton & Pretty, 2010; Felsten, 2009; Hartig et al., 2003; Orsega-Smith et al., 2004; Ulrich, 1984; Van den Berg & Ter Heijne, 2005; Zadeh et al., 2014)	Nonvisual connection to nature (Alvarsson et al., 2010; Koga & Iwasaki, 2013; Pheasant et al., 2010; Ratcliffe et al., 2013; Ulrich et al., 1991; Van den Berg et al., 2003)	Presence of Plant (Bringslimark et al., 2007; Dijkstra et al., 2008; Knight & Haslam, 2010; Larsen et al., 1998; Nieuwenhuis et al., 2014; Qin et al., 2014; Shoemaker et al., 1992; Thomsen et al., 2011)	Presence of Animals (Ratcliffe et al., 2013; Windhager et al., 2011)	Dynamic &diffuse light/season (Küller & Lindsten, 1992; Nicklas & Bailey, 1996)	Biomorphic forms &patterns (Hagerhall et al., 2004; Herzog & Bryce. 2007; Herzog & Kropscott, 2004; Joye, 2007)	Material connection with nature (Joye, 2007; Koga & Iwasaki, 2013; Lichtenfeld et al., 2012; Nyrud et al., 2014; Schatz & Bowers, 2005; Tsunetsugu et al., 2007; Reddy et al., 2012)	Presence of natural images (Beute & de Kort, 2013; Brown et al., 2013; Chang & Chen, 2005; Felsten, 2009; Herzog, & Kropscott, 2004; Hunter et al., 2010; Kjellgren & Buhrkall, 2010; Lee et al, 2015; Nyrud et al., 2014; Pheasant et al., 2010; Ulrich et al., 1991; White et al., 2010; White & Gatersleben, 2011; Van den Berg et al., 2003)	Simulated natural light and air (Reddy et al., 2012)	Prospect and refuge (Gatersleben & Andrews, 2013)	Mobility & Transitional spaces (Beute & de Kort, 2013; Hartig et al., 2003; Van den Berg et al., 2003)	Place (Küller & Lindsten, 1992; Korpela et al., 2009)	Risk/Peril (Herzog & Kropscott, 2004; Herzog & Bryce, 2007)
Promoting Attention restoration	2	1 & 2		1			1	3		2	2		
Appeal aesthetic /attraction/interesting		2	2			1		2			2		
Preferences		1 & 2	2	1		1 & 2	1 & 2	3			2		2
Positively impacted attitude/Positive affects/ pleasure arousal	2	2				1	1	3		2	2		
Positive emotion/mood responses	2	1	2	1			1						
Negative mood	2							2					
Induce tranquility		2						2					
Feel relax/Restoration			2	1			2						
Low sense of fear/ Perceived fear		1 & 2						2		2			
Low anger aggression	2	2					1	2		2	2		
Low tension	2										2		
Low anxiety/stress	2	2	2	1			1 & 2	2			2		
Low depression/Sadness	2	1 & 2						2			2		
Perceived of danger	2							2		2			2
Pleasure		2					2						
effortless attention		1		1									
Psychological health		1	2						1				

	Direct experience of nature					Indirect experience of nature				Space and place			
	Visual connection to nature (Barton & Pretty, 2010; Felsten, 2009; Hartig et al., 2003; Orsega-Smith et al., 2004; Ulrich, 1984; Van den Berg & Ter Heijne, 2005; Zadeh et al., 2014)	Nonvisual connection to nature (Alvarsson et al., 2010; Koga & Iwasaki, 2013; Pheasant et al., 2010; Ratcliffe et al., 2013; Ulrich et al., 1991; Van den Berg et al., 2003)	Presence of Plant (Bringslimark et al., 2007; Dijkstra et al., 2008; Knight & Haslam, 2010; Larsen et al., 1998; Nieuwenhuis et al., 2014; Qin et al., 2014; Shoemaker et al., 1992; Thomsen et al., 2011)	Presence of Animals (Ratcliffe et al., 2013; Windhager et al., 2011)	Dynamic &diffuse light/season (Küller & Lindsten, 1992; Nicklas & Bailey, 1996)	Biomorphic forms & patterns (Hagerhall et al., 2004; Herzog & Bryce. 2007; Herzog & Kropscott, 2004; Joye, 2007)	Material connection with nature (Joye, 2007; Koga & Iwasaki, 2013; Lichtenfeld et al., 2012; Nyrud et al., 2014; Schatz & Bowers, 2005; Tsunetsugu et al., 2007; Reddy et al., 2012)	Presence of natural images (Beute & de Kort, 2013; Brown et al., 2013; Chang & Chen, 2005; Felsten, 2009; Herzog, & Kropscott, 2004; Hunter et al., 2010; Kjellgren & Buhrkall, 2010; Lee et al, 2015; Nyrud et al., 2014; Pheasant et al., 2010; Ulrich et al., 1991; White et al., 2010; White & Gatersleben, 2011; Van den Berg et al., 2003)	Simulated natural light and air (Reddy et al., 2012)	Prospect and refuge (Gatersleben & Andrews, 2013)	Mobility & Transitional spaces (Beute & de Kort, 2013; Hartig et al., 2003; Van den Berg et al., 2003)	Place (Küller & Lindsten, 1992; Korpela et al., 2009)	Risk/Peril (Herzog & Kropscott, 2004; Herzog & Bryce, 2007)
Overall happiness	2	2						2			2		
Familiarity	2	2									2		
Complexity								2			2		2
Fascination	1 & 2	1		1				2			2		
Being away	1 & 2							2					
Extent	1 & 2							2					
Compatibility	1 & 2							2			2		
Mystery				1		1 & 2							
Legibility						1 & 2							
Coherence													2
place attachment												2	
Improve mental engagement attentiveness								2		2			
Positive impact on cognitive performance					2		1		1				
Increase productivity			2				1		2				
Enhanced creativity							2						
Improve communication	2												
Concentration			2		2								
Social interaction	2												
Decrease sleepiness	2												
Decrease sick leave			2										

	Direct experience of nature					Indirect experience of nature				Space and place			
	Visual connection to nature (Barton & Pretty, 2010; Felsten, 2009; Hartig et al., 2003; Orsega-Smith et al., 2004; Ulrich, 1984; Van den Berg & Ter Heijne, 2005; Zadeh et al., 2014)	Nonvisual connection to nature (Alvarsson et al., 2010; Koga & Iwasaki, 2013; Pheasant et al., 2010; Ratcliffe et al., 2013; Ulrich et al., 1991; Van den Berg et al., 2003)	Presence of Plant (Bringslimark et al., 2007; Dijkstra et al., 2008; Knight & Haslam, 2010; Larsen et al., 1998; Nieuwenhuis et al., 2014; Qin et al., 2014; Shoemaker et al., 1992; Thomsen et al., 2011)	Presence of Animals (Ratcliffe et al., 2013; Windhager et al., 2011)	Dynamic &diffuse light/season (Küller & Lindsten, 1992; Nicklas & Bailey, 1996)	Biomorphic forms & patterns (Hagerhall et al., 2004; Herzog & Bryce. 2007; Herzog & Kropscott, 2004; Joye, 2007)	Material connection with nature (Joye, 2007; Koga & Iwasaki, 2013; Lichtenfeld et al., 2012; Nyrud et al., 2014; Schatz & Bowers, 2005; Tsunetsugu et al., 2007; Reddy et al., 2012)	Presence of natural images (Beute & de Kort, 2013; Brown et al., 2013; Chang & Chen, 2005; Felsten, 2009; Herzog, & Kropscott, 2004; Hunter et al., 2010; Kjellgren & Buhrkall, 2010; Lee et al, 2015; Nyrud et al., 2014; Pheasant et al., 2010; Ulrich et al., 1991; White et al., 2010; White & Gatersleben, 2011; Van den Berg et al., 2003)	Simulated natural light and air (Reddy et al., 2012)	Prospect and refuge (Gatersleben & Andrews, 2013)	Mobility & Transitional spaces (Beute & de Kort, 2013; Hartig et al., 2003; Van den Berg et al., 2003)	Place (Küller & Lindsten, 1992; Korpela et al., 2009)	Risk/Peril (Herzog & Kropscott, 2004; Herzog & Bryce, 2007)
State of consciousness								2					
Satisfaction (job, workplace)			2				1						
Self-esteem	2							2					
Motivation							1						
Self-confidence			2										

Note. 1 = Indicates a relationship between the biophilic patterns, even though outcomes are not yet directly supported by empirical studies; these may be influenced by biophilic patterns.

2 = Indicates a relationship between biophilic patterns and outcomes that is supported by empirical studies (< 5 papers).

3 = Indicates strong evidence of a relationship between biophilic patterns and outcomes and significant results from multiple types of research (≥ 5 papers).

An empty cell indicates that a relationship between the biophilic patterns and the outcome has not yet been determined.

2.1.7.2. Biophilic Patterns and Physiological Health

According to Hung, S.H., and Chang (2021), Table 2 lists the physiological effects that were discovered utilizing equipment to measure heart rate, blood pressure, cortisol levels, and other physiological markers, as well as a questionnaire designed to comprehend how the body reacts to stress. Similar results were obtained for psychological health and well-being. In addition to other advantages, stress is reduced, the heart rate and blood pressure are reduced when there are visual and non-visual links to nature, plants, and light (Hartig et al., 2003; Küller and Lindsten, 1992; Ulrich et al., 1991; Zadeh et al., 2014). Hunter et al. (2010) discovered that, compared to viewing a freeway, viewing a beach influences a stronger sense of tranquility and activates the connection between the auditory and perception areas in the brain. Pheasant et al. (2010) also suggested that perceived stimulation from the environment and the visual-auditory interactions thereof can affect a sense of tranquility. The use of natural analogs, such as natural materials, can reduce stress, according to Tsunetsugu et al. (2007).

Table 2: Biophilic Patterns and Physiological Health (Hung, S.H. and Chang, 2021).

	Direct experience of nature				Indirect experience of nature			Space and place	
	Visual connection to nature (Hartig et al., 2003; Orsega-Smith et al., 2004; Zadeh et al., 2014)	Nonvisual connection to nature (Alvarsson et al., 2010; Jahncke et al., 2011; Reddy et al., 2012; Ulrich et al., 1991)	Presence of Plant (Qin et al., 2014; Thomsen et al., 2011; Ulrich, 1984)	Dynamic &diffuse light/season (Küller & Lindsten, 1992)	Material connection with nature (Joye, 2007; Koga & Iwasaki, 2013; Tsunetsugu et al., 2007)	Presence of natural images (Brown et al., 2013; Chang & Chen, 2005; Hunter et al., 2010; Kjellgren & Buhrkall, 2010; Tsunetsugu et al., 2007; Ulrich et al., 1991)	Simulated natural light and air (Reddy et al., 2012)	Prospect and refuge (Gatersleben & Andrews, 2013)	Mobility & Transitional spaces (Van den Berg et al., 2003)
Low blood pressure					2	2			
Low heart rate (BVP)	2					2		2	
SDRR						2			
Decrease in diastolic blood pressure (DBP)	2				2	2			2
Decrease in systolic blood pressure (SBP)	2				2	2			2
Frontalis muscle tension (EMG)		2				2			
Electroencephalogram (EEG)			2			2			
Less pain						2			
Reduce skin conductance level(SCL)	2	2							
Gain energy						2			
overall (Perceived) physical health	2	2	2				1		
Brain activity						1&2			
Body temperature	2								
Blood oxygen	2								
Cortisol				2					
Pulse transit time(PTT)		2		2					
Oxyhaemoglobin				2	2				

Note. 1 = Indicates a relationship between the biophilic patterns, even though outcomes are not yet directly supported by empirical studies; these may be influenced by biophilic patterns.
2 = Indicates a relationship between biophilic patterns and outcomes that is supported by empirical studies (< 5 papers).
An empty cell indicates that a relationship between the biophilic patterns and the outcome has not yet been determined.

2.2. Biophilia and Natural Ventilation

2.5.1. Properties of Natural Ventilation

Although there has always been natural ventilation, our buildings have developed into sophisticated heat machines. However, natural ventilation more than makes up for this lack of control with ease of use and efficiency. Currently, many technical alternatives offer substantially greater control over the flow of fresh air and thermal comfort than a simple facade opening. According to past studies (Oropeza-Perez, and Østergaard, 2014; Bienvenido-Huertas et al., 2020; Rackes et al., 2016), natural ventilation has a great potential for energy savings, especially in warmer climates. The condition of the outside air has the biggest impact on the thermal comfort restrictions of natural ventilation. Usually, these limitations only apply to air temperatures between 20 and 26 C (Axley and Emmerich, 2002).

According to Aviv et al. (2021), natural ventilation is the exchange of air between an object's interior and exterior. Wind-driven ventilation (induced by pressure differences generated by the wind blowing around the building) and "stack effect" ventilation (caused by temperature fluctuations) are two examples of natural ventilation. Natural ventilation is the process of bringing outside air inside a building. The unclean, heated air in the rooms is forced outside by the fresh air from the roof hole. This can be used without any mechanical help. It is one of the most effective methods for reducing energy use in buildings. It makes use of the wind's and buoyancy's inherent capacity to spread fresh air throughout buildings for the benefit of people. It is controlled by the pressure variations between the inside and outside of a building, or between its different sections.

Nearly all older buildings had natural ventilation. Natural ventilation has gained prominence as people have learned more about the price of energy use and its effects on the environment. Instead of the more common approach of using mechanical ventilation, this is an ideal alternative for reducing energy usage and expense, providing permissible inner environmental conditions, and maintaining a healthy and comfortable indoor climate. Natural ventilation can be used as an alternative to HVAC units in favorable climates, saving 10%–30% of total energy use (Aviv et al., 2021).

2.5.2. Benefits of Natural Ventilation

Maintaining a healthy lifestyle is made easier by natural ventilation. For instance, the oxygen in the fresh air can raise energy levels and lower blood pressure. It aids in strengthening the immune system. Higher serotonin levels also boost the feeling of rejuvenation and sleep. Through a strong link to the dynamics of the environment, natural ventilation can offer a sufficient supply of breathing air, appropriate ventilation of pollutants, sufficient thermal conditioning, and humidity waste. Natural ventilation is typically chosen by designers because it reduces carbon emissions and costs less to install and maintain than fully mechanical ventilation. Additionally, it requires less maintenance, alters the expectations of the occupants, and gives them more environmental control. By providing free night cooling, this sort of ventilation lowers daytime temperatures.

In general, it is difficult to give definitive answers about the benefits and drawbacks of natural ventilation compared to mechanical systems, largely because these factors are influenced by outside factors including how a building is used and the changing temperature. Nevertheless, certain broad reasons can be provided because this subject of natural ventilation cannot be avoided. When properly installed and maintained, natural ventilation systems have several advantages over mechanical ones. Due to the use of natural forces and big openings, natural ventilation can theoretically provide a high ventilation level more cheaply. They use less energy, particularly if heating is not required. Higher levels of daylight could be provided by using well-designed systems.

The maintenance of a sustainable building environment is the other major benefit cited for natural ventilation. This argument is difficult to justify given that natural ventilation has been used for thousands of years. One factor in this is that a natural system does not require electrical energy for fans, which can account for 25% of the electrical energy used in a facility that is mechanically ventilated. There are records indicating that residents desire not to be completely cut off from the outside world and that they wish to regulate their environment. Both of these conditions can be met by natural ventilation, but they cannot be met by a typical air conditioner. The benefit of natural ventilation is that it may provide a very high air-change level for little money and with a very simple system. Buildings with modern ventilation systems (that are modeled and operated effectively) can attain very high air-change levels by natural power, which can considerably be

more in quantity than minimal ventilation needs. This is true even though the air-change rate can vary significantly.

On the other side, natural ventilation systems have several drawbacks. Natural ventilation fluctuates and is dependent on the outside climate in relation to the interior environment. Temperature differential and wind are the two driving elements that unintentionally affect the airstream rate. Natural ventilation can be challenging to manage because the airstream might be static in some places and uncomfortable and heavy in others. Lack of consistent negative pressure might cause issues with monitoring the direction of the airstream; as a result, it is dangerous to pollute hallways and adjacent rooms.

The use of particle filters is avoided through natural ventilation. Windows and vents may need to remain closed for reasons of security, culture, and temperature; in these cases, the ventilation level may be substantially lower. It only works when natural power is available; a high ventilation level necessitates a high requirement for natural power accessibility. Normal operation of natural ventilation systems may be interrupted for a variety of reasons, including failure of doors or windows to open, equipment destruction, utility service interruption (if it is a high-tech system), inadequate modeling, improper management, or poor preservation. Natural ventilation systems typically do not perform as anticipated. Because of a lack of funding, a ventilation system's operation may be altered, increasing the risk of the transfer of airborne diseases even though the preservation cost of natural ventilation systems can be extremely low.

Natural ventilation also has the drawback of having a limited capacity to provide cooling in hot areas, especially ones that are also humid. It is important to combine this system with some sort of bearable (low-energy) cooling system for it to be acceptable in some climates. It does not require additional room for plant rooms or duct networks; however, some locations are frequently required for stacks (chimneys, atria). The specific drawback is that mistakes made when simulating a natural system could be more challenging to correct. It's also important to be aware of other potential issues including air pollution, insect vectors, noise, and security. However, these issues can be resolved, for example, by employing improved modeling or hybrid (mixed-mode) ventilation.

2.5.3. Mechanism of Air Distribution

2.2.3.1. Wind-Driven

Wind-driven ventilation is the simplest mechanism of air distribution. It is also known as cross ventilation and unilateral ventilation. This kind of ventilation depends on how the wind behaves and how it interacts with the building's chimneys, windows, and other openings. Misconceptions about wind-driven ventilation are common. People believe that increasing ventilation can be accomplished by opening windows. Even if the outside wind speed is just ideal, air conditioning can significantly increase energy expenses. Figure 3 presents the wind-driven mechanism.

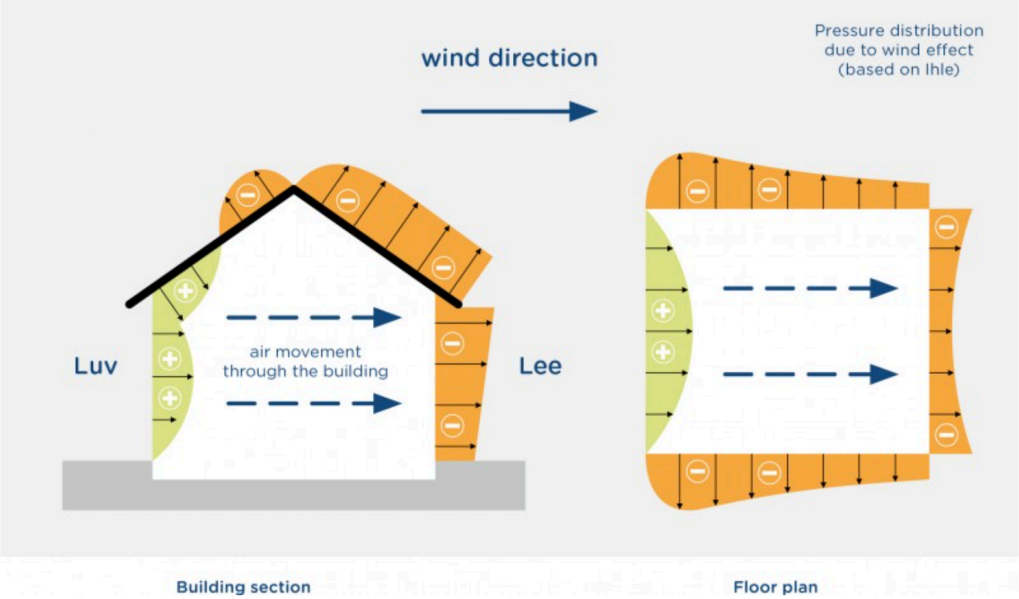

Figure 3: Influence of Wind and Thermal Updraft on Ventilation (regel-air.com).

2.5.4. Challenges of Using Natural Ventilation in Biophilic Designs

The present biophilic design movement was sparked by the initial biophilia hypothesis put forth by E.O. Wilson in 1984. He described biophilia as the “innately emotional affiliation of human beings to other living organisms. Innate means hereditary and hence part of ultimate human nature” (Wilson 1984). Wilson asserted that a human's need to interact with nature and natural forces is inbuilt. The built environment was the next area in which S.R. Kellert and E.O. Wilson used this idea (1993). Working in a naturally green and plant-like atmosphere was only one aspect

of the concept. It was first put into practice in Kellert's recommended qualities for biophilic design (2008), in which he established the main terms, concepts, and features of the field. Kellert highlighted place-based/vernacular and organic/naturalistic as the two main dimensions. "Shapes and forms in the built environment that directly, indirectly, or symbolically reflect the inherent human affinity for nature" are referred to as having an organic dimension (Kellert 2008). "Buildings and landscapes that connect to the culture and ecology of a location or geographic area" are referred to as having a vernacular component (Kellert 2008).

This last component, as noted by Kellert, also involves a sense or spirit of place. Six major categories are then further divided into more than 70 biophilic design characteristics. There are more sophisticated qualities as well, such as sensory diversity, information richness, exploration, and discovery, or a geographic, historic, ecological, and cultural link to a place. These qualities are as basic and obvious as the presence of water, air, sunlight, plants, and animals. The environment can be an atmosphere, a process, or an experience, which is crucial for biophilic designers to comprehend. Architecture is lifeless if it does not have an atmosphere and a sense of place. If designers want biophilic design to be meaningful and a positive lived experience, it is vital to recognize atmospheres, ambiances, energies, mediation, and experiences.

According to Kellert's view, some clearly defined elements and traits are subject to change, while others can be improved over time. The 14 Patterns of Biophilic Design - Improving Health and Well-Being in the Built Environment by Terrapin Bright Green is one of the most recent revisions to Kellert's work. The 14 biophilic design patterns are divided into three categories: patterns inspired by nature, natural analogs, and patterns inspired by space. Another is the Biophilic Interior Design Matrix (McGee et al. 2019), which takes Kellert's work and operationalizes it for interior environments to provide designers with more concrete and understandable direction.

Kellert (2008) has discussed some of the challenges that designers have when implementing biophilic design in real-world settings, particularly when including conceptual and abstract design elements. Many people desire clear guidelines that they can use in their designs or that can be incorporated into modeling software because biophilic design is not always obvious in its guidelines. A holistic approach and a profound awareness of both human and non-human environmental aspects and components - their purpose and relationship that forms the overall

atmosphere - are required to fully appreciate the patterns and characteristics of biophilic design. Examples include the lived experience, which is what architecture is ultimately about. Effective biophilic designers need to be extremely skilled at both rational and irrational aspects of space design. In addition to having a sense of humor, they must comprehend all aspects of space and the human experience, including mental, sensory, temporal, natural, cultural, traditional, etc. This method of approaching nature's benefits does not always align well with health-nature scientific evidence that employs a psychometric research paradigm. This can cause a disconnect, which can then be expressed as ignorance of pre-existing health-nature research or as a challenge translating biophilic attributes into design objectives that can be measured and quantified.

2.3. Ventilation and Thermal Comfort

The current ventilation systems aim to improve the level of the environment, making it more convenient and comfortable for users. In studies conducted by Jamaludin (2014) and Haruna (2014), thermal comfort was determined as the most important measure of satisfaction degree in the vacuum. On the contrary, studies conducted by Markus (1980) and Jamaludin (2014) have shown the negative impact of thermal discomfort, which may cause physical and psychological problems for users.

The goal of thermal comfort is to achieve a balanced and consistent heat exchange rate between users and their environment (Yoon, 2008). According to Jamaludin (2014) and Yoon (2008), this is achieved through several factors including the physiological, cultural, and social conditions of the population, as well as environmental factors related to this study including air temperature, mean radiant temperature, relative humidity, air velocity, and turbulence intensity.

2.5.1. Thermal Comfort Parameters and Conditions for Human Occupancy

One of the main functions of ventilation is to provide thermal comfort and acceptable quality of indoor air by controlling several environmental parameters. Therefore, it is worth considering the main parameters of thermal comfort such as air temperature, operative temperature, relative humidity, air velocity, and turbulence intensity (Cui et al., 2013; Spentzou, 2015; Wigö, 2013).

2.3.1.1. Air Temperature

According to a study conducted by Yoon (2008), indoor air temperature is classified as the main parameter for measuring the degree of thermal comfort. Numerous studies on indoor air temperature and its relationship to thermal comfort have shown that reaching a vacuum temperature within the comfort zone increases the productivity and efficiency of users (Cui et al., 2013). On the other hand, thermal discomfort is closely related to the phenomenon of SBS (Seppänen et al., 2004; Kolarik et al., 2007).

2.3.1.2. Operative Temperature

According to the Chartered Institution of Building Services Engineers (CIBSE, 2006), the operative temperature is considered a better and more accurate measure of thermal comfort than air temperature because it is calculated based on the air temperature and the Mean Radiant Temperature (MRT) by taking the average. It differs from the (MRT) by first taking into consideration the impact of convection and radiation in heat exchange (Spentzou, 2015; CIBSE, 2006). On the other hand, Matzarakis (2007) added that the MRT is a variable that affects the body heat exchange through radiation, so it is known as the temperature of the assumption enclosure surrounding the surface. In this case, the subject heat exchange through radiation and the environment's actual radiation are equal.

A study conducted by Walikewitz (2015) stated that because it is a variable that depends on different parameters this makes it is difficult to measure it. Due to the importance of this variable and to facilitate its handling, the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) developed a model of adaptation that defined acceptable comfort zones in mechanically ventilated spaces depending on the characteristics of the space, its function, and the number of users.

Depending on the classification and assessments of ASHRAE standard 55 - 2017, Figure 4 clarifies the acceptable range of operative temperature and humidity for spaces that meet the criteria specified in the ASHRAE standards Section 5.2.1.1.

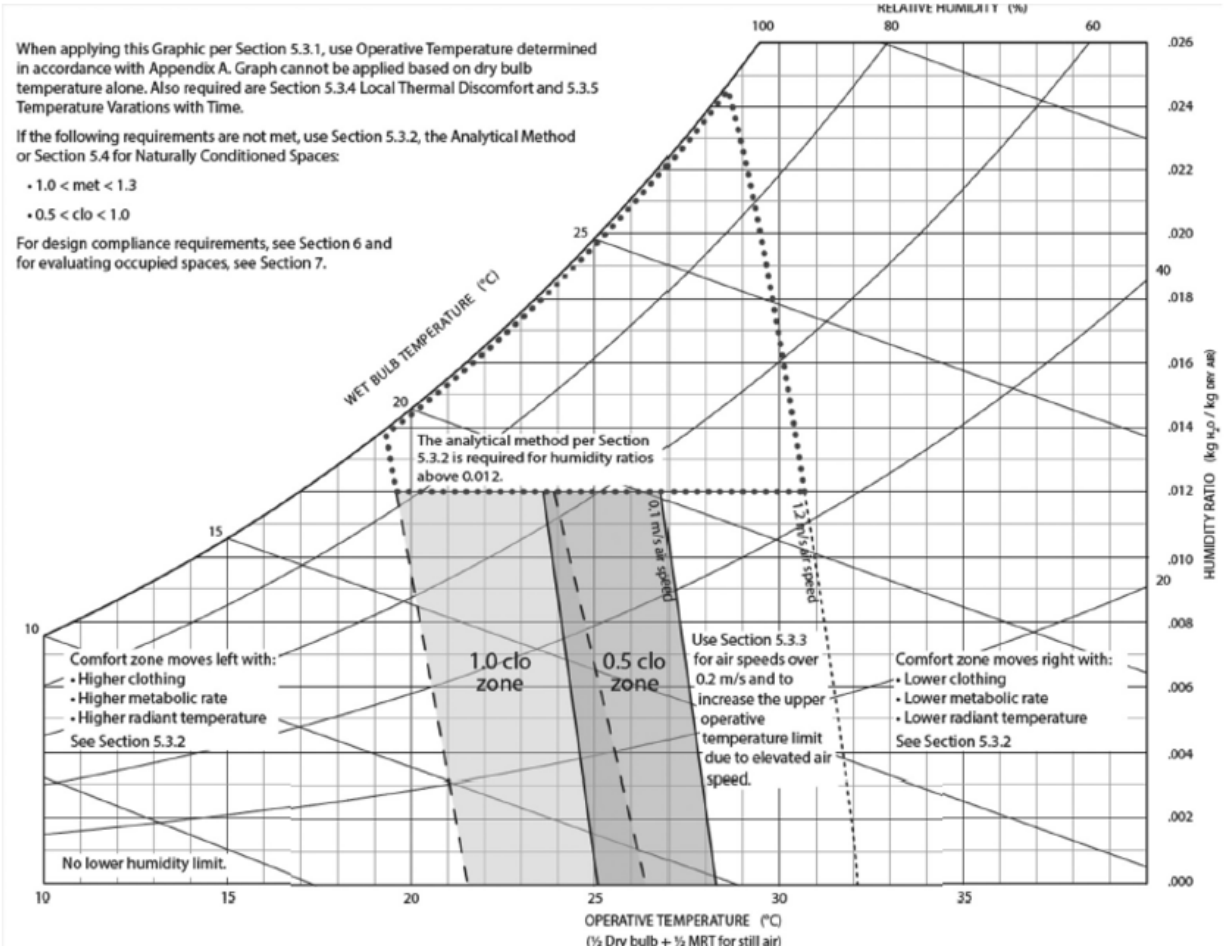

Figure 4: The acceptable range of operative temperature and humidity for spaces that meet the criteria specified in ASHRAE Standard 55 – 2017, Section 5.2.1.1

2.3.1.3. Relative Humidity

Fang (2004) argued that the importance of relative humidity lies in its ability to provide a comfortable indoor environment if appropriate humidity levels are available, and its impact on the activities of users and their sense of thermal comfort. Therefore, a study conducted by Alsmo (2014) indicated that low levels of relative humidity affect users and may cause them health problems such as dry and irritated eyes, and dryness of the outer skin of the body. Besides, the results of the studies conducted by Seppänen (2004) and Alsmo (2014) indicated that high humidity above the acceptable limit is harmful to users' health because it is an environment suitable for the multiplication of bacteria, insects, and mold.

It should be noted that obtaining a certain degree of humidity in the internal vacuum is related to the temperature of the vacuum and this is illustrated by the diagram produced by

ASHRAE and shown in the previous section, figure 5. The diagram shows the relationship between operative temperature and relative humidity and indicates that relative humidity ratios should be between 30-60% according to ASHRAE standards 55-2017.

2.3.1.4. Air Velocity

Airflow velocity plays a crucial role in determining the comfort levels of individuals in indoor spaces. The air movement can significantly influence thermal comfort, perceived freshness, and overall well-being. Striking the right balance is essential to create an environment where occupants feel comfortable and productive.

The air velocity affects the perceived temperature experienced by individuals. Higher airflow may lead to increased evaporative cooling, making individuals feel cooler even at higher ambient temperatures. On the other hand, low or stagnant airflow may result in a feeling of warmth, especially in spaces with poor ventilation. This has been confirmed by the standards of ASHRAE 55 - 2017 which stressed the inverse relationship between the air velocity in the vacuum and the degree of the user's thermal comfort. Achieving the optimal airflow velocity is essential for maintaining thermal comfort in indoor environments.

2.3.1.5. Turbulence Intensity

Turbulence intensity is an important parameter in the indoor environment, allowing engineers and designers to construct a space that meets the needs of occupants. Turbulence intensity can be defined as the rate of fluctuation of air velocity inside space and it is usually expressed as a percentage of the steady-state air velocity. High turbulence intensity can lead to several problems, including reduced thermal comfort and increased energy consumption due to an increase in ventilation, making it important to quantify and measure turbulence intensity for indoor environments.

The standard for acceptable turbulence intensity in indoor environments is largely dependent on the specific use of space. To measure and analyze turbulence intensity, many different techniques have been developed. These include both real-time measurements as well as CFD simulations. Real-time techniques are generally used to measure the instantaneous air velocity at certain points within a space and these can be combined with Lagrangian or Eulerian

calculation models to obtain a spatiotemporal map of the turbulence intensity. CFD simulations are more suited for predicting the behavior of turbulence intensity before construction and design begin, as they can simulate the flow characteristics of space much more accurately.

Overall, understanding and measuring turbulence intensity is important for designing and constructing indoor environments that meet acceptable standards. Accurate measurements and computational simulations can be used to get an indication of how turbulence intensity may affect space and how this can be mitigated or managed. By doing so, engineers and designers can ensure that their designs are comfortable and safe, while also using the least amount of energy possible.

2.4. Current Ventilation System and Airflow in Architecture

To balance the indoor temperature and/or ventilation, HVAC systems are used. Radiant or convective-dominant techniques can both reduce indoor heat load. System-recirculated air (RA) is thermally conditioned in terms of temperature and humidity in the convective-dominant technique. To reduce indoor pollutants like CO_2, a convective-dominant method must be used, in which fresh air (FA) or conditioned outdoor air (COA) is produced by filtering and thermal conditioning outside air. FA can be provided in a variety of methods, either individually or in combination with RA. Ventilation methods can be classified as fully mixed or non-uniform based on airflow characteristics.

2.5.1. Types and Properties of Mechanical Ventilation Systems

Mechanical ventilation systems play a crucial role in maintaining indoor air quality and thermal comfort. Several types of ventilation systems, each with distinct properties, are employed in various settings.

1. **Mixing Ventilation (MV):**

Initially designed for thermal comfort, MV focuses on supplying air at high velocity close to the ceiling to achieve homogenous indoor settings. However, this design may lead to energy inefficiency and compromised air quality, especially in the presence of point sources of pollutants.

2. **Diffuse Ceiling Ventilation (DCV):**

DCV allows external air to enter the space with low velocity, controlled by buoyancy forces. It is suitable for environments like classrooms, offering homogeneous airflow patterns. However, DCV may face challenges in spaces with high ceilings and limited cooling capability.

3. **Displacement Ventilation (DV):**

Utilizing buoyancy forces, DV creates a stratified flow, improving air quality in the occupied zone. DV is energy-efficient, provides longer free cooling periods, and is commonly used in spaces like gyms, conference rooms, and museums.

4. **Under Floor Air Distribution (UFAD):**

UFAD employs a plenum beneath a raised floor to distribute conditioned air through floor diffusers. This system offers increased flexibility, lower life-cycle costs, and improved thermal comfort, particularly in commercial structures with raised floors.

5. **Stratum Ventilation (SV):**

SV creates a sandwich airflow field, suitable for small to medium-sized rooms. It proves effective in reducing CO_2 emissions and life cycle costs compared to MV, making it suitable for offices, classrooms, and conference spaces.

6. **Impinge Jet Ventilation (IJV)/Confluent Jets Ventilation (CJV):**

IJV uses impinging jets for ventilation, while CJV involves circular jets. These systems are effective in various settings, such as industrial buildings, classrooms, and offices, but require careful design consideration for thermal comfort.

7. **Wall Attached Ventilation (WAV):**

Combining elements of MV, DV, and impinging jet flow, WAV is suitable for spaces with irregular shapes, offering cost savings and improved cooling efficiency.

8. **Intermittent Air Jet Strategy (IAJS):**

IAJS involves rapid variations in ventilation flow rate, reducing stagnation zones and draft risks. While effective for cooling demand reduction, it may face limitations in fixed sitting arrangements and increased noise.

9. **Protected Occupied Zone Ventilation (POV):**

POV aims to create a protected zone using low-turbulence aircraft jets, suitable for open-plan workplaces or isolation rooms. Hybrid POV combines with other airflow distribution systems for enhanced contaminant control.

10. **Personalized Ventilation (PV):**

PV delivers fresh air to individual occupants, reducing Sick Building Syndrome (SBS) symptoms. While effective, PV requires careful design considerations, including airflow direction and flow rate adjustments.

11. **Local Exhaust Ventilation (LEV):**

LEV is an extract ventilation system suitable for spaces with localized contamination sources, such as commercial kitchens. Careful calculation of airflow rates is essential to optimize system efficiency.

12. **Laminar Airflow (LAF)/Piston Ventilation (PiV):**

LAF creates a piston-like flow for contamination control, mainly used in clean rooms and operating rooms. However, it can be expensive and may lead to increased post-operative Surgical Site Infections (SSI).

In summary, the choice of mechanical ventilation system depends on factors such as space size, occupancy, and specific requirements. PV, with its focus on individualized airflow, has been chosen for further development as a biophilic airflow system.

2.5. Personalized Ventilation

2.5.1. Benefits of Personalized Ventilation Unit

The PV has two key advantages over total volume air distribution: first, it has the potential to improve the quality of the air that is breathed in; and second, each occupant has been given the authority to customize and control the temperature, flow rate (local air velocity), and direction of the locally supplied personalized air in accordance with their preferences, thereby improving the conditions of their thermal comfort.

Physical measures show that using PV compared to using Total Volume ventilation (TV) significantly lowers the amount of pollution inhaled air (Bolashikov et al., 2003; Cermak and Melikov, 2003; Cermak and Melikov, 2004; Cermak et al., 2004; Faulkner et al., 1993; Faulkner et al., 1999; Faulkner et al., 2003; Melikov et al., 2002; Melikov et al., 2003; Zuo et al., 2002). Most Air Terminal Devices (ATDs) have only been able to operate at their best when between 50 and 60 percent of the inhaled air is pure. It is now possible to boost ventilation efficacy by at least 20 times when compared to mixing ventilation because of the development of highly effective ATD that provide virtually 100% clean and cool personalized air to be inhaled by the user (Bolashikov et al., 2003; Melikov et al., 2003). When compared to mixed ventilation, the temperature of the air that is inhaled may be lowered by up to 6 °C (in warm indoor environments), which will enhance the perceived quality of the air.

People's thermal comfort is increased by PV (Kaczmarczyk, 2003; Kaczmarczyk et al., 2004; Kaczmarczyk et al., 2002; Yang et al., 2003; Zeng et al., 2002). At room temperatures over 23 °C, the thermal environment with PV is substantially more tolerable than it is without PV. The ability to control supply airflow rate, or local air velocity, makes it evident that draught discomfort can be avoided. Although it significantly improves whole-body thermal comfort, at room air temperatures above 26 °C, the cooling capacity of the personalized flow targeting a relatively small body surface area may not be sufficient to provide some people with thermal comfort without causing draught discomfort (Sekhar et al., 2003; Yang et al., 2003).

In-depth research has been done on the interaction of flow near the breathing zone and its significance for the user's comfort in terms of temperature, perceived air quality, and cleanliness of the air they are inhaling (Bolashikov et al., 2013; Bolashikov et al., 2013; Licina et al., 2015; Licina et al., 2015; Bolashikov et al., 2017; Kierat et al., 2018). Design and positioning recommendations for the ATD, PV supply flow rate, and temperature, control of the supplied airflow's properties, and its interaction with the free convection flow already present around the human body have all been made (Bolashikov et al., 2009; Bolashikov et al., 2010; Melikov, 2015; Melikov and Dzhartov, 2013).

Compared to TV, the PV has a stronger ability to stop the spread of infection among occupants when correctly designed and implemented. The use of PV in MV-equipped rooms always shields people from the spread of infectious pathogens through the air and is superior to mixed ventilation alone (Melikov et al., 2003). However, PV encourages the mixing of room air and exhaled air in spaces with displacement ventilation (Cermak et al., 2004; Cermak et al., 2006; Melikov et al., 2003). In rooms with underfloor ventilation, a comparable effect might take place (Cermak et al., 2003; Cermak et al., 2004; Cermak et al., 2007). In practice, this could raise the danger of airborne infectious agent transmission to occupants not covered by high-efficiency PV.

A localized/personalized exhaust device was included in a different study's health-based PV performance enhancement in a mock-up healthcare clinic scenario (Junjing et al., 2014; Yang et al., 2015). A seat with integrated Personal Exhaust (PE) and PV has been proposed for use in car interior applications, and it has been tested using both human subjects and physical measures (Melikov et al., 2012; Melikov et al., 2013). The results offered unambiguous proof of the PV-PE system's efficiency in preventing airborne infections.

When using PV, there have been reports of significant energy savings in terms of energy performance. PV can give thermal comfort to users at higher room temperatures, between 25 and 27 °C, due to convective cooling of the body (Bauman et al., 1993; Kaczmarczyk et al., 2004; Melikov and Knudsen, 2007). Significant energy savings (up to 60%) are observed when PV plus MV is employed at a higher room temperature compared to TV alone (Bauman et al., 1998; Schiavon at al., 2010; Seem, 1992; Sekhar et al., 2005; Sekhar et al., 2010). In warm and humid outdoor settings, combining PV that supplies clean outdoor air with background MV based on

cleaning and recirculating interior air is very energy efficient, primarily because less energy is required for dehumidifying the outside air.

At a 100% peak cooling load, the integrated PV-ACB system could save 16% of energy, and at a 25%-part cooling load, it could save as much as 42% of energy, demonstrating the system's better energy-saving potential (Sekhar and Zheng, 2018). According to Lybenova et al. (2011), when PV is combined with background MV, the air supplied to the room may be reduced by as much as 20% (and as much as 40% when the room temperature is increased by 2°C above the upper limit advised in the standards) when compared to MV alone. The supplied air was reduced by up to 80% when PV and passive chilled beams were used together.

The use of a PV unit in the home can provide occupants with numerous psychological, well-being, and physiological benefits. This type of unit is designed to provide optimal air temperature and humidity levels that are tailored to each person’s individual needs and preferences. By doing this, it effectively creates an indoor environment that is comfortable, safe, and enjoyable.

One of the primary benefits of using a PV unit is improved indoor air quality. This type of system utilizes an advanced filtration system to remove allergens, dust, pollen, smoke, and other contaminants from the air. This helps to ensure a cleaner, healthier indoor air environment, which can help to reduce the risk of respiratory illness, allergies, headaches, and eye irritation. Additionally, PV units provide improved temperature and humidity control, which can help to create a more pleasant and comfortable living atmosphere. This can be beneficial for occupants who are sensitive to hot or cold temperatures, as well as those with conditions such as arthritis or fibromyalgia that can be worsened by extremes of temperature.

Mental and emotional health benefits can also be seen when using a PV unit. The increased sense of comfort and safety that comes from having optimal temperature and humidity levels can help to reduce stress and anxiety levels. Furthermore, improved air quality can help occupants breathe more easily, which can improve concentration, energy levels, and overall mood.

Also, the use of a PV unit can help to promote wellness by providing a better sleeping environment. Not only can this type of system help to reduce allergies and provide optimal

temperature and humidity levels, but it can also help to reduce noise pollution. This can lead to more restful and restorative sleep, which can in turn help to reduce the risk of a variety of health issues such as obesity, diabetes, and heart disease.

In conclusion, there are numerous health, well-being, and wellness benefits that occupants can experience when using a PV unit. From reduced respiratory illness symptoms to improved mood and energy levels, this type of system can help to create an environment that is comforting, safe, and conducive to overall health and wellness.

2.5.2. Mechanism of Air Distribution

In general, the ATDs used for PV are located close to the occupant's breathing zone. Using different designs of ATDs allows more control for airflow direction and rate. Several designs have been tested. studies tested using two small nozzles placed at the back corners of a desk (Faulkner et al., 1993; Faulkner et al., 1995; Faulkner et al., 1999; Sodec, 1990), or using two linear diffusers placed at the front desk edge (Cermak and Melikov, 2003; Cermak and Melikov, 2004; Cho et al., 2004; Faulkner et al., 2003; Melikov, 2004; Melikov et al., 2002). Other studies used rectangular or circular openings mounted on a movable arm-duct (Bolashikov et al., 2003; Melikov et al., 2002), or a flat ATD mounted on the top of a PC monitor (Melikov et al., 2002). On the other side, other studies focused on supplying air very close to the occupant's breathing zone by using a small nozzle integrated with the flexible support of a commercially available headphone (Bolashikov et al., 2003), or by used circular nozzle attached to the chest blowing air against the face (Zuo et al., 2002), or ventilation tower system (Hiwatashi et al., 2000). Other studies designed PV for chairs where the air is supplied through a pillow behind the head, a neck rest, or part of the chair (Nielsen, 2008; Nielsen et al., 2008; Nielsen et al., 2007).

With all the benefits of PV, supplied air close to occupants' faces may cause several problems. According to Wyon and Wyon (1987), it may make them feel uncomfortable, cause skin irritation, or increase eye blinking. But these problems may be solved by changing the room air temperature and relative humidity. According to (Melikov et al., 2011), the eye blinking frequency may be decreased by increasing the room temperature and relative humidity to became 26-28 °C and 70% rather than 23°C and 40%. Also, using PV may affect the stability of the tear film.

According to (Melikov et al., 2013), users in warm environments that use PV, a temperature of 26-28 °C, and relative humidity of 70%, felt that their tear film stability improved.

2.6. Summary

In conclusion, as discussed in this chapter, the previous studies focused on developing the indoor environment and enhancing human indoor life. Researchers work hard in several disciplines to develop indoor ventilation, increase the inhaled air, improve the quality of the inhaled air, and try as much as they can to expand the comfort zone and increase the number of satisfied occupants. It is important to mention that, for achieving these goals, previous studies mainly depended on developing mechanical devices to produce steady mechanical air movement. But none of these studies worked on using mechanical devices to produce natural airflow. They focused on producing a steady airflow that may let occupants feel satisfied and finish their work successfully. Whereas, unfortunately, over time most of these products affected occupants negatively by separating them from the outside environment, letting them feel lazy, reducing their performance and productivity, and affecting their physiological, psychological, and well-being.

On the other hand, even when previous studies focused on developing air movement in indoor environments, they did not think about this from a biophilic point of view. Researchers mostly thought about developing the air movement for economic, industrial, commercial, and sometimes health purposes. But they did not think about improving indoor ventilation as a biophilic design. They did not think about reconnecting occupants with the outdoor environment and nature by combining the biophilic principles with the architectural designs as airflow. This is what tries to be achieved through this study. This research focuses on moving from developing mechanical air movement to developing more natural air movement and shifted the thinking from developing rigid architectural designs to developing more biophilic architectural designs that may enhance the occupants' experiences, reconnecting them to nature that may positively affect them. This research suggests developing a BLNAS as a developed biophilic system that will produce and mimic natural airflow.

3.Chapter Three: Research Methodology

3.1. Introduction

This chapter discusses the methodology that was adopted in conducting this study. Based on the nature of the research and its requirements, and as a broader approach to thinking about it, the research consists of four main phases: determining the natural airflow characteristics, experimental design and setup, data analysis, and selection and design of the prototype. To achieve these phases, quantitative method was applied.

3.2. Qualitative vs Quantitative

In general, using qualitative and quantitative techniques in designing the BLNAS is an important part of creating an effective product that meets occupants' needs. Qualitative techniques involve the iterative nature of product design. On the other hand, quantitative techniques involve using statistical methods or computer simulations to measure performance, environmental impacts, energy efficiency, cost-effectiveness, etc. Both methods play an essential role in the design process and should be used in conjunction when creating a BLNAS.

Qualitative techniques can help designers gain a better understanding of what users would want out of a BLNAS. This kind of information is incredibly helpful in making sure the product that is created meets expectations. These techniques allow designers to gain an understanding of what features users would prefer in the product, such as noise level, airflow rates and patterns, and aesthetic appeal. Based on the feedback from users, designers can make changes and improvements to the product design before it goes into production.

Quantitative techniques are also important for determining the performance and efficiency of the BLNAS. By using statistical techniques and computer simulations, designers can evaluate different factors such as air velocity, air pressure, temperature, turbulence intensity, and humidity levels, to improve the understanding of how the product will interact with the indoor environment. Additionally, a cost analysis can be used to determine how many resources and materials are needed to manufacture the product.

Ultimately, both qualitative and quantitative techniques are necessary for the design process when creating a BLNAS. The application of qualitative techniques can help designers understand user perspectives while supporting the explorative and iterative nature of design. By using both methods together, designers can create a product that meets expectations, performs well, and is cost-effective for consumers.

This research aims to use mainly quantitative tactics to produce a prototypical biophilic natural airflow system that simulates natural airflow; to create healthier and more comfortable indoor environments by changing the indoor airflow characteristics. The quantitative technique was used for the first and third phases which were related to determining the characteristics of natural airflow and analyzing the airflow data collected at the location of an occupant seated at the workstation.

Based on this, Figure 5 illustrates the seven major stages of the research including introduction, literature review, methodology, data collection, experimental test setup, results and discussion, and architectural design recommendations.

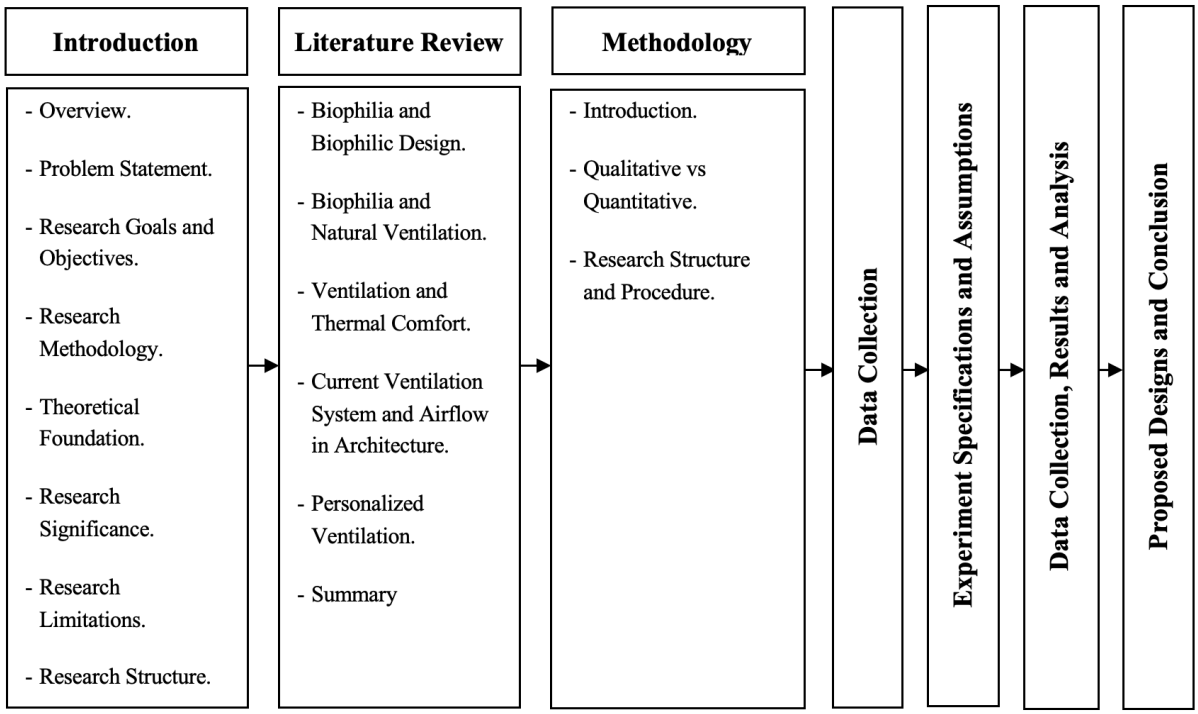

Figure 5: Main Research Stages (Illustrated by the Author).

3.3. Research Structure and Procedure

This section explains the structure and procedures that were implemented to answer the research questions to achieve the stated goals and objectives. Figure 6 presents a chart of the research structure and procedures. The research methodology was divided into four main phases as presented in Figure 6;

1. Phase 1: Determining Natural Airflow Characteristics.
2. Phase 2: Experimental Design and Setup.
3. Phase 3: Data Analysis.
4. Phase 4: Selection and Design of the Prototype

As mentioned in section 1.4, to determine the physiological and psychological benefits of the prototypical system, additional phases are needed that are beyond the scope of the current research. For example, phase five will determine the interaction of the prototypical system with the mechanical system and its' forced air distribution, while phase six will assess the performance of the prototype. But, due to the limitations of funding, time, and resources, the researcher did not work on these two additional phases and will approach them as future research.

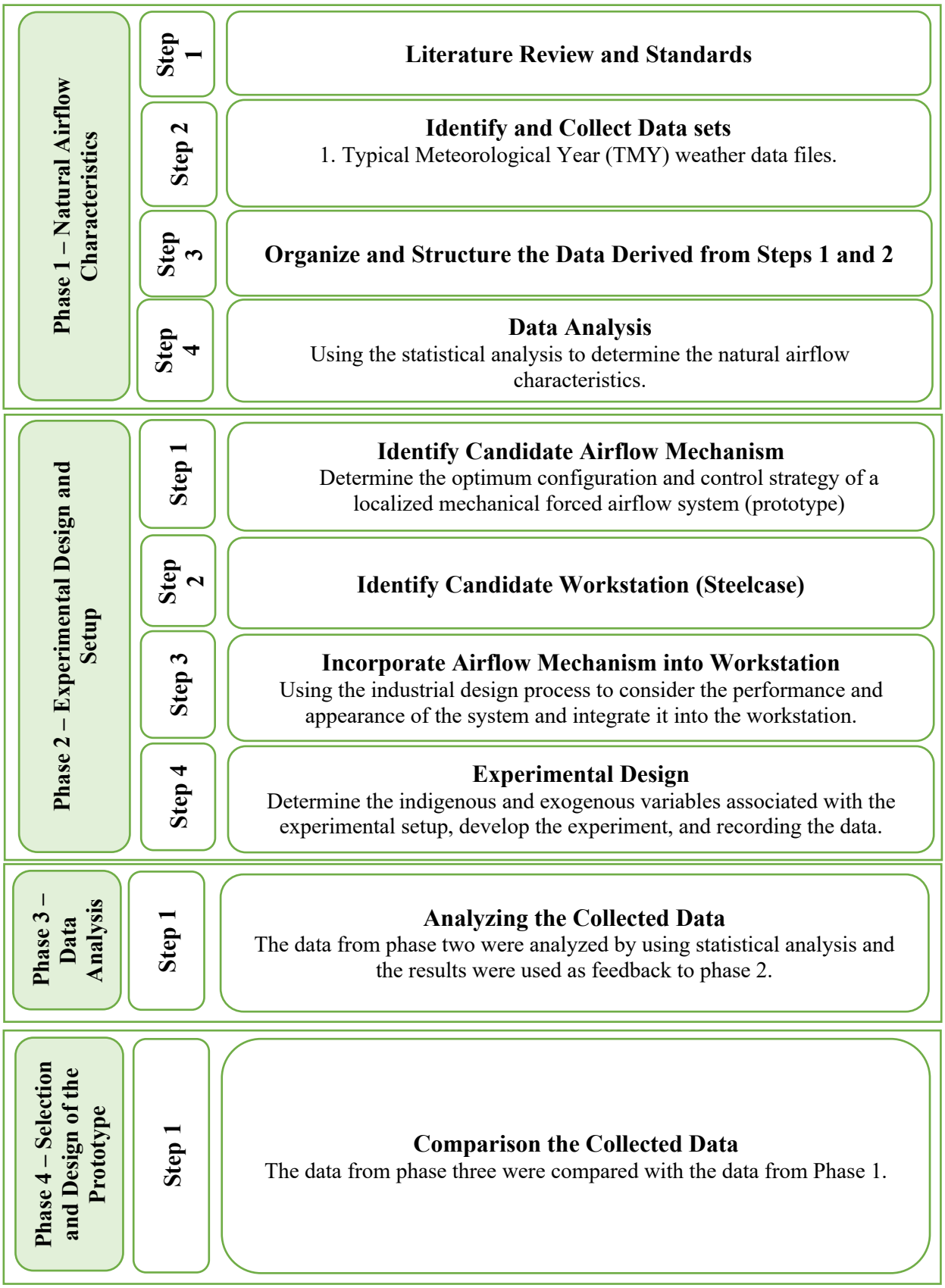

Figure 6: Research Structure and Procedure (Illustrated by Author).

To answer the research questions and achieve the stated objectives the research methodology was divided into four main phases; the determination of natural airflow characteristics, the experimental design and setup, the data analysis, and the selection and design of the prototype. Below is a description of all phases and their related steps.

1. Phase One: Determine the Natural Airflow Characteristics

Phase one of this research seeks to determine the characteristics of natural airflow. Phase one consists of four main steps:

1.1 Determine the characteristics and features of natural airflow based on literature, and related standards.
1.2 Identify and collect the characteristics and features of natural airflow based on the available weather data files.
1.3 Organize and structure the data from steps one and two.
1.4 Statistically analyze the data from step 3 to determine the characteristics and features of "natural" airflow.

To achieve the intended biophilic benefits of the proposed system, the characteristics that differentiate natural airflow from typical indoor mechanical airflow need to be determined. This required the analysis of outdoor air characteristics such as the temporal mean speed variations and turbulence intensity. For that, outdoor wind data was collected and partitioned to limit data to outdoor conditions when natural airflow would be most appropriate. This corresponded to the Adaptive Thermal Comfort model as proposed by ASHRAE.

2. Phase Two: Experimental Design and Setup

Phase two of this research was concerned with the experimental design and setup and determining the indigenous and exogenous variables associated with the BLNAS. It consists of four steps as follows;

2.1 Identify and determine the candidate airflow mechanism.
2.2 Identify candidate workstation.
2.3. Incorporate airflow mechanism into the modular workstation.

2.4 Experimental design.

2.1. Step One - Identify and determine the candidate airflow mechanism

For step one, the results from phase one were applied to determine the optimum configuration and control strategy of a localized mechanical forced airflow system. For this, alternative forced-air devices (fans) and their control sub-system were evaluated to choose which device would best meet the research objectives. Then the chosen system was experimentally set up and tested, and the resulting airflow was statistically compared to the desired "natural" airflow characteristics as determined in phase one.

2.2. Step Two: Identify the candidate workstation

For step two, the candidate workstation was determined and identified. For this, cooperation with the Steelcase Company was established to support this research with the donation of one of their representative workstations. The workstation was at the Global Forum for Urban and Regional Resilience (GFURR) office. More details about the workstation are available in Section 5.2.

2.3. Step Three: Incorporate the airflow mechanism into a modular workstation

For step three, the airflow device selected in step one was applied to the modular workstation from step two. Once the workstation was delivered the mechanical forced airflow system from step one was integrated with it. For this, an industrial design process was used to integrate the system into the workstation. The design process considered the performance and appearance of the airflow device and workstation.

2.4. Step Four: Experimental Design

For step four, the research variables associated with the BLNAS, and experimental setup were determined. For this, the indigenous and exogenous variables associated with the system performance were determined, the workstation and alternative localized airflow devices were set up, and the airflow at the location of a seated occupant was monitored and recorded. For measuring and recording the data, a TSI model 8465 Hot Wire Transducer and sensor were set up at the occupant seating position. Measurements were taken every 10 seconds for the 99 different speeds

of the mechanical device. The collected data were organized, structured, and partitioned for analysis and the results were used to develop the prototype by choosing the best design configuration and approach for integration with the workstation.

3. Phase Three: Data Analysis

Phase three of this research is related to data analysis. It consists of one step as follows;

3.1. Step one – Analyzing the collected data

For step one of phase three, the data from phase two were analyzed statistically. The results of this phase were used as feedback for phase two to develop and enhance the experiment and develop the prototype.

4. Phase Four: Selection and Design of the Prototype

Phase four of this research is related to the selection and design of the prototype. It consists of one step as follows;

4.1. Step one – Comparison the collected data

For step one of phase four, the analyzed data from phase three were compared. For this, statistical analysis was performed to compare the airflow characteristics at the location of the seated occupant with those of natural airflow from phase one. The approach with the highest correlation between the localized system and the natural flow target was selected as the best alternative for the design of the prototype.

Table 3 presents the research questions, the corresponding methodological steps, the methods that were used, and the expected results.

Table 3: The Research Questions and Answering Procedure (Illustrated by the Author).

Research Question	Research Step	Method of Investigation	Expected Result
1. What are the fundamental attributes and properties that define natural airflow patterns?	Phase 1 Step 1 – Step 4	1. Literature. 2. Standards. 3. Typical Metrological Year (TMY).	Determine the characteristics and features of natural airflow.
2. Is it possible to conceptualize, design, and develop a localized airflow system that accurately replicates the essential characteristics of natural airflow?	Phase 2 – Step 1	Evaluate the Advantages	Determine the optimum configuration and control strategy of a localized mechanical forced airflow system and choose the device that will best meet the research goals
	Phase 2 Step 2 – Step 3	Industrial Design Process – Incorporate the Mechanical Forced Airflow Mechanism into a Modular Workstation considering the performance and appearance of the system	Incorporate the mechanical forced airflow system (prototype) into a modular workstation.
	Phase 2 – Step 4	Logical Argumentation	Determine the indigenous and exogenous variables associated with the experimental setup and development of the prototype.
	Phase 2 – Step 4	Experimental Testing – By Setting Up the Workstation, Prototype, TSI model 8455 Hot Wire Transducer, and sensor at the occupant seating.	Design the experimental setup and record the airflow patterns data at the occupant seating. Organize, structure, and partition the collected data
	Phase 3 – Step 1	Statistical Analysis	Analyze the collected data.
	Phase 4 – Step 1	Statistical Analysis	Compare the collected data about the airflow characteristics at the location of the seated occupant with those of natural airflow from Phase one and

	determine the best prototype that may simulate natural airflow.

4.Chapter Four: Data Collection

4.1. Natural Airflow Characteristics

This chapter explains the procedures used to collect data related to the characteristics of natural airflow. It mainly explains the procedures used to determine the characteristics of natural airflow by focusing on the data found in literature, related standards, and simulation software data files.

4.1.1. Literature

Based on the published standards for human comfort the accepted range for the airflow was identified. He et al. (2020) mentioned that Pendwarden and Wise (1975) classified the relationship between outdoor human comfort and airflow velocity into five main levels as shown in Table 4. This means that in order to maintain thermal comfort the airflow velocity from the prototype should not exceed 5 m/s which is equal to 11.18 mph.

Table 4: The relationship between human comfort and airflow velocity (Pendwarden and Wise, 1975).

Airflow Velocity (m/s)	Airflow Velocity (mph)	Comfort
1<V<5	2.24<V<11.18	Comfortable
5<V<10	11.18<V<22.37	Uncomfortable
10<V<15	22.37<V<33.55	Very Uncomfortable
15<V<20	33.55<V<44.74	Intolerable
20<V	44.74<V	Dangerous

4.1.2. ASHRAE Standards

In accordance with ASHRAE standard 55: Thermal Environmental Conditions for Human Occupancy, human comfort in indoor environments is evaluated based on six key factors including air temperature and airflow rate. ASHRAE suggests specific temperature ranges for optimal comfort, including a range of 20.3ºC - 23.8 ºC (68.5 ºF - 75 ºF) in the winter and 23.8ºC – 26.9 ºC (75 ºF – 80.5 ºF) in the summer.

It is important to note that these values and the associated comfort zone limits may be influenced by airflow velocity. Therefore, the natural airflow characteristics become essential when considering the acceptability of the indoor environment. The recommended temperature range by ASHRAE aligns with specific airflow conditions.

However, in the context of this research, and the focus on natural ventilation and considering the adaptive comfort model, it is pertinent to recognize the limitations of ASHRAE standards. The adaptive comfort model takes into account subjective factors such as individual metabolic rates, clothing choices, and other user-related considerations. This model provides a more flexible approach to determining comfort levels as it recognizes the subjective nature of human comfort.

In light of the research findings and the emphasis on natural ventilation, it is recommended to extend the temperature range beyond the ASHRAE guidelines. Based on the concept of comfortable natural airflow velocity, this research proposes a revised temperature range of 68 - 83°F. This adjustment is made in acknowledgment of the adaptive comfort model, which offers a more nuanced and user-specific understanding of indoor comfort. By integrating the adaptive comfort model into the analysis, the proposed temperature range aims to better capture the diverse factors influencing occupant satisfaction in natural ventilation scenarios and try designing a prototype that might give the users personal controllability to their comfort zone. There are some reasons for this extension as follows;

1. Enhanced Airflow Dissipation: Increasing the airflow velocity within a space can have a significant impact on the perception of comfort. Higher airflow rates facilitate better heat dissipation from the human body. Expanding the temperature range will account for the fact that individuals can tolerate a wider range of temperatures when exposed to a comfortable airflow. This adaptation increases the range of conditions under which natural airflow patterns can be considered conducive to comfort in indoor environments.
2. Local Thermal Comfort: ASHRAE's recommended comfort temperature typically assumes a uniform indoor environment, with minimal airflow. However, natural airflow may lead to variations in temperature within space. Extending the temperature range will allow for

localized fluctuations, recognizing that the perception of comfort may differ in areas with more or less direct airflow.

For that, for the purpose of this research, the natural airflow characteristics were determined in terms of airflow velocity and airflow temperature, and they are 1 - 5 m/s equal to 2.24 – 11.18 mph and 68-83 °F, respectively.

4.2. Determining the Location of Study

The choice of an appropriate study climatological location is an important aspect of this research, one that aims to determine the natural airflow characteristics for that location, while demonstrating a process that could be adapted to other locations. This section outlines the process of determining the study location, incorporating criteria derived from the literature for outdoor thermal comfort, and ASHRAE standards. Subsequently, it describes the selection of three representative locations in the United States - Blacksburg, Virginia, Honolulu, Hawaii, and Los Angeles, California - and the evaluation of their weather data sets based on the determined natural airflow characteristics. The section culminates in the selection of Blacksburg as the research location and the use of its weather data set as a reference for the research experiment.

4.2.1. Selection of Representative Locations

Determining natural airflow characteristics requires a comprehensive understanding of the environment and its climatic conditions. Climatic conditions play a crucial role in determining airflow characteristics and using data from multiple climatic zones can provide a more accurate representation of the natural airflow characteristics. For that, and while this research was focused on the U.S., three different climatic zones were taken into consideration. These different climatic zones represented a range of climatic conditions which was intended as a better estimate for the average of the natural airflow characteristics in the U.S. while reducing bias. Analyzing data from multiple climatic zones might provide a more robust representation of the desired natural airflow characteristics.

For that, the researcher depended on the ASHRAE climate zones map to select the representative locations. Figure 7 represents ASHRAE's world climate zones map and Figure 8 represents ASHRAE's North America climate zones map. Figure 7 and Figure 8 have a color-coded legend with alphanumeric codes ranging from 0A to 8. These codes represent different climate zones defined by ASHRAE standards for building design and energy efficiency. The color gradient starts with a deep purple at the bottom, indicating the code "0A" which stands for extremely hot climates, and goes up to a light blue, labeled "8" indicating polar or very cold climates.

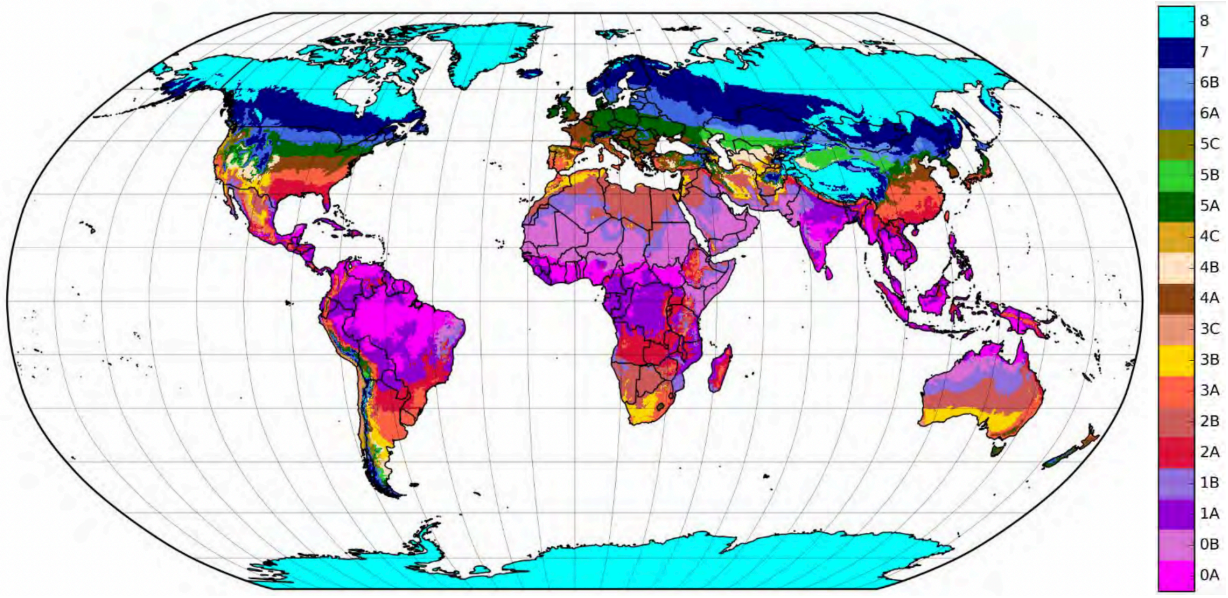

Figure 7: ASHRAE World Climate Zones Map (ASHRAE-2020).

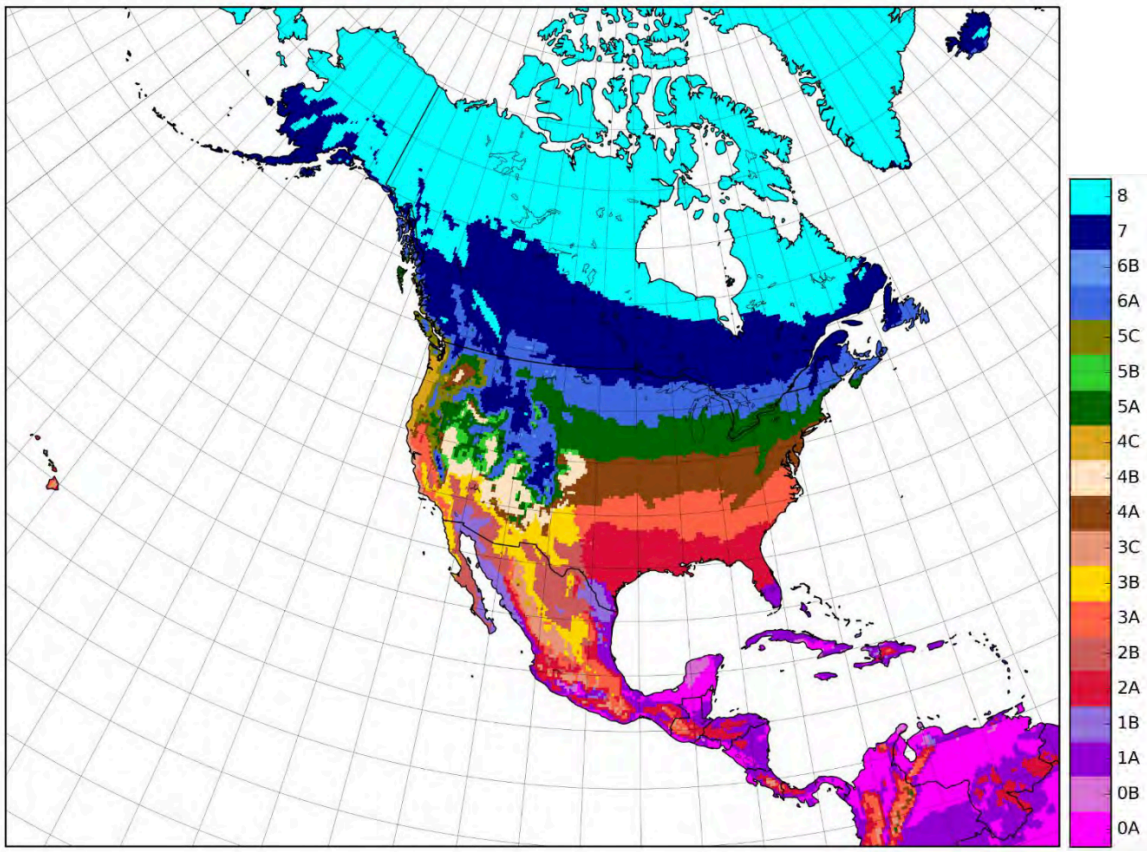

Figure 8: ASHRAE North American Climate Zones Map (ASHRAE-2020).

By focusing on Figure 8, the North American climate zones map, and moving from the top of the map down to the south it's obvious that;

1. A large section of dark blue across the northernmost parts of Canada and Alaska, which corresponds to the coldest climate zones categorized as "7" or "8" in the ASHRAE legend. These zones are characterized by polar or very cold conditions.
2. Progressing south, there are lighter shades of blue over a broad area that includes much of Canada and parts of the northern United States, indicating cooler climate zones typically numbered "6A" or "6B".
3. Further south, a band of green stretches across the central part of the United States, indicative of temperate climate zones likely numbered "5".
4. Transitioning down through the map, there is a wide belt of yellow and orange, suggesting warmer climate zones labeled "3" or "4".

5. At the southernmost regions of the United States and Mexico, and extending into Central America, the map displays areas of red and deep red, which correspond to hot and very hot climates, labeled "0", "1", or "2" in the ASHRAE system.

The map in Figure 8 shows the diversity of climates within North America, ranging from the frigid arctic zones in the far north to the tropical and subtropical zones in the south. These classifications are important for choosing the representative locations and to determine the natural airflow characteristics. Based on this, and for the purpose of this research, three locations within the United States were initially chosen as representative of different climatic zones; Blacksburg, Virginia, Honolulu, Hawaii, and Los Angeles, California. These locations were selected for their potential to exhibit favorable natural airflow patterns and their capacity to represent a range of climates found in the United States.

Blacksburg, located in the Appalachian region of Virginia, was chosen as a representative location for temperate, continental climate conditions. It is characterized by variable seasonal temperatures and geographical setting, within the Appalachian Mountain range. Whereas Los Angeles, situated in Southern California, offers a unique Mediterranean climate characterized by mild, wet winters and hot, dry summers. Its coastal proximity and diverse topography provide an opportunity to explore how coastal and mountainous influences affect natural airflow. On the other hand, Honolulu, located on the island of Oahu in Hawaii, presents a tropical climate environment, influenced by trade winds and surrounded by the Pacific Ocean. The selection of Honolulu as a study location allows for the examination of tropical airflow patterns in contrast to continental and Mediterranean climates. These three locations have characteristics that make them ideal candidates for assessing natural airflow.

4.2.2. Data Collection

To conduct a comprehensive analysis of natural airflow characteristics in these locations, it was crucial to collect high-quality weather data. This was achieved by checking the weather data files from simulation software like Climate Consultant. A second option was accessing data from an on-site monitoring station. Available wind monitoring sites near Blacksburg, VA, were identified, and collaboration was sought, such as with the Virginia Tech airport weather station. The issue with this option was the large number of recorded measurements being 0 m/s, making it

difficult to analyze and determine natural airflow characteristics. A third option was setting up a wind monitoring station and recording data on-site. However, this was the least desirable option due to its time and resource-intensive nature. Consequently, TMY files extracted from Climate Consultant software were chosen for this research.

TMY files provide users with hourly, daily, and monthly weather data sets, which can be used to determine the climatic conditions of a specific location. Climate Consultant software, a reliable and widely recognized source for weather-related information, was used to extract TMY files for the three representative locations.

The hourly, daily, and monthly data sets for the three locations were extracted from Climate Consultant. In the first stage, for each month a comparison was made between the hourly windspeed values and the previously identified acceptable range for natural airflow characteristics. Table 5 presents the monthly airflow speeds in mph for Blacksburg, Honolulu, and Los Angeles.

Table 5: Monthly Airflow Speeds in mph for Blacksburg, Honolulu, and Los Angeles (Climate Consultant).

	Airflow Speed (mph)		
Month	**Blacksburg, VA**	**Honolulu, HI**	**Los Angeles, CA**
January	7.7604094	10.326266	7.448021
February	7.0340185	11.229931	6.5020814
March	7.024688	9.693373	8.39932
April	6.4852386	10.983336	8.864464
May	4.7492704	14.276677	8.365042
June	3.586236	13.801872	8.199598
July	3.4771662	12.324472	8.670816
August	4.092623	14.501877	6.2934756
September	3.4526424	11.329747	7.1758904
October	4.507237	9.650074	6.7739344
November	4.052886	12.170774	7.10754
December	7.2910748	12.582743	5.299485

Based on Table 5, the relationship between the monthly airflow speeds for the representative locations and the natural comfort airflow speed range was analyzed and presented in Figure 9.

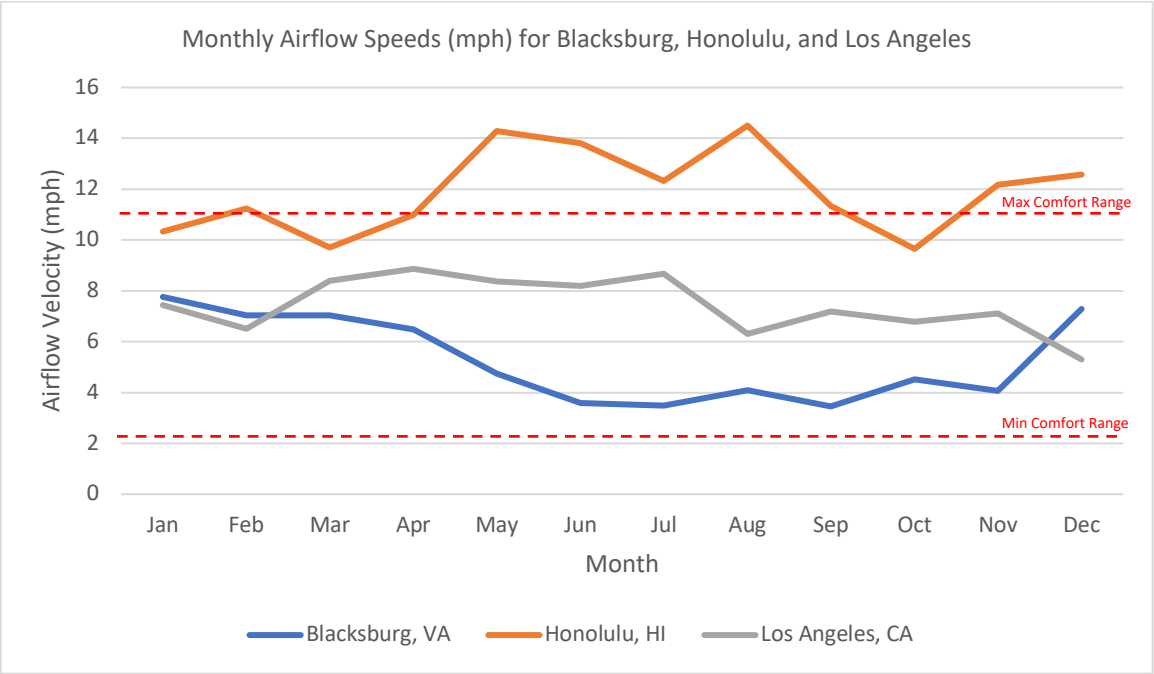

Figure 9: Monthly Airflow Speeds (mph) for Blacksburg, Honolulu, and Los Angeles and the Natural Comfort Airflow Speed Range.

Based on the data presented in Table 5 and Figure 9, it was obvious that Honolulu is mostly out of the natural comfort range where 8 months have a velocity above the range and just 4 months fall within the comfort range. While Honolulu experiences higher wind speeds, it might be comfortable because the higher wind speeds compensate for the higher temperature. But using these higher temperatures might pose challenges for maintaining indoor comfort levels, particularly without adequate cooling systems. Therefore, despite Honolulu's favorable weather, the combination of high temperatures and airflow speeds renders Honolulu mostly out of the natural comfort range for indoor environments. For that, Honolulu was excluded from the suggested representative locations. On the other hand, Blacksburg and Los Angeles are totally within the natural airflow comfort range for all months. For that, they were selected as representative locations.

On the other hand, it should be recognized that the natural airflow patterns change within a short time, sometimes within only a few seconds. For that, and to make a deeper and more accurate analysis, the hourly data sets for Blacksburg and Los Angeles were extracted. Each of the two data sets has a total of 8760 data points (hourly values) for the full year. However, some of the data points were out of the comfort range. For that two filters were applied to the hourly data sets. The first filter was for temperature, and only selected data points in the desired range (68 – 83 °F). The second filter was for the airflow velocity and was applied to extract data points in the determined range (2.24 – 11.18 mph).

By applying these two filters, two new data sets were developed where the data points were within the natural airflow comfort range. Blacksburg's data set consists of 1252 data points while Los Angeles's data set consists of 958 data points. The difference of 294 data points between the two data sets led to choosing Blacksburg as a representative location for this research due to its larger data set and the more variable natural airflow. Table 6 presents a sample of filtered data sets for Blacksburg and Los Angeles. The full filtered data sets are available in Appendix A.

Table 6: Sample of the Filtered Hourly weather data sets for Blacksburg and Los Angeles.

Blacksburg		**Los Angeles**	
Temperature (°F)	**Airflow Velocity (mph)**	**Temperature (°F)**	**Airflow Velocity (mph)**
68	10.289887	69.08	5.816023
68	9.171421	69.08	9.171421
70.88	9.171421	69.08	9.171421
68	8.052955	69.98	8.052955
71.96	10.289887	71.06	5.816023
71.96	6.7107964	69.08	8.052955
69.98	8.052955	71.06	9.171421
68	6.7107964	75.02	4.697557
74.84	10.289887	69.08	10.289887
75.92	6.7107964	69.98	8.052955

Based on the filtered data set for Blacksburg, statistical analysis was applied to calculate the minimum, mean, maximum, median, and standard deviation. Table 7 presents these values. In

conclusion, the results show that the comfort natural airflow velocity in Blacksburg varies between 2.46 mph and 10.96 mph with a mean of 6.058 mph, and the median and standard deviation were 5.816 and 2.147, respectively.

Table 7: Statistical Analysis for Blacksburg's Filtered Airflow Velocity (mph) Data Set.

Blacksburg, VA				
Min	**Mean**	**Max**	**Median**	**SD**
2.4606254	6.05813397	10.960967	5.816023	2.14772063

Another statistical analysis was performed to calculate the data distribution pattern. Based on the full data set for Blacksburg, the distribution for the airflow velocity was calculated and presented in Figure 10. Also, the comfort airflow velocity range was overlayed with the distribution to determine and present the natural airflow velocity zone as shown in Figure 10. Based on this, it was obvious that the Blacksburg data is not totally within the natural airflow comfort range, but the majority of its values are within the range. Based on the filtered data set, the distribution for the natural comfort airflow velocity was calculated and presented in Figure 11.

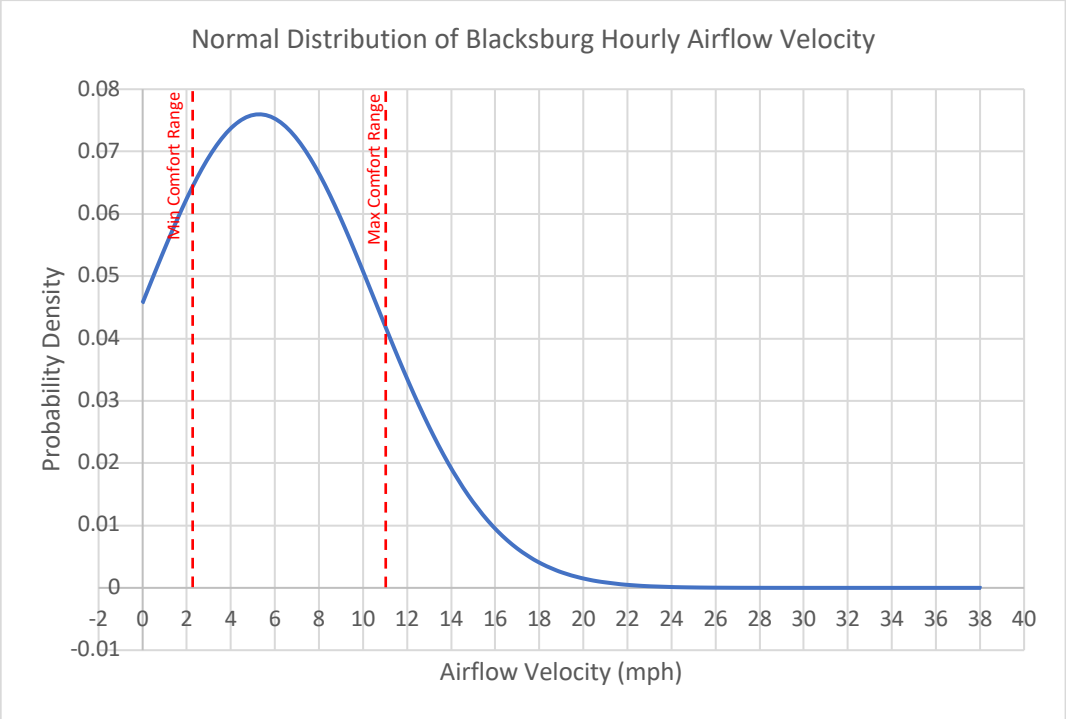

Figure 10: Normal Distribution of Blacksburg Hourly Airflow Velocity and the Natural Comfort Airflow Speed Range.

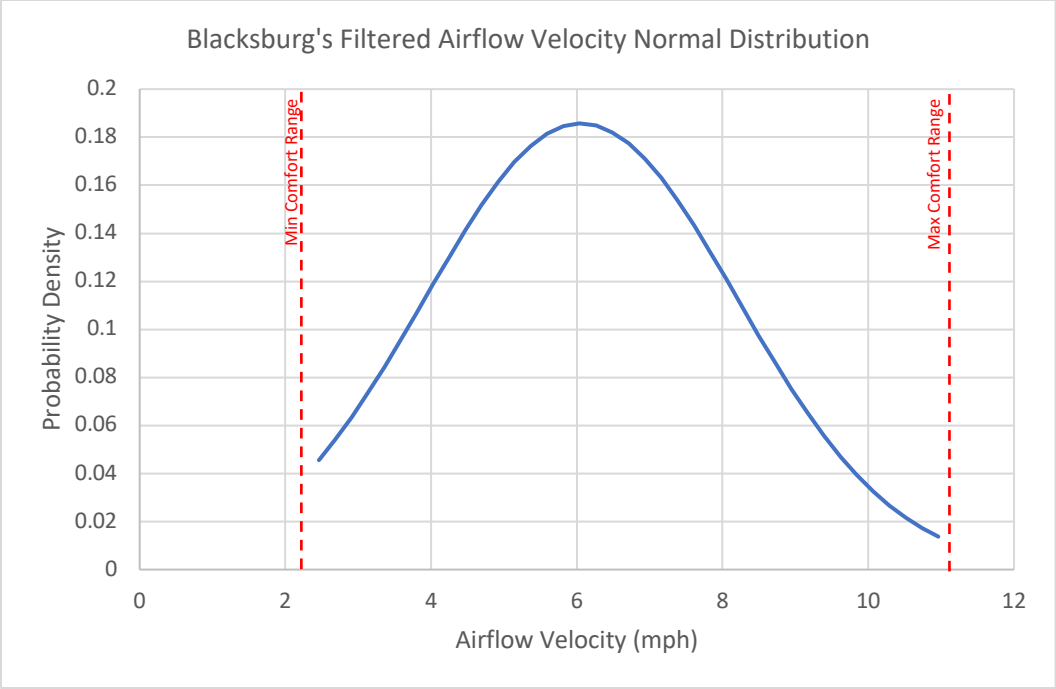

Figure 11: Blacksburg's Filtered Airflow Velocity Normal Distribution and the Natural Comfort Airflow Speed Range.

In addition to these analyses, it was important to take into consideration that TMY files provide the users with hourly data sets where natural airflow variability has a smaller time scale (around a few seconds). For that, Turbulence Intensity (TI) was calculated based on the filtered data sets to achieve the desired variability of natural airflow and to understand the fluctuations in its patterns. Based on this, the TI for the comfort range of natural airflow velocity was calculated. Table 8 presents a statistical analysis for Blacksburg's filtered TI data set and Figure 12 presents Blacksburg's filtered hourly TI graph. Later on, the normal distribution and TI graphs were used to compare the natural airflow variability with the variability produced by BLNAS.

Table 8: Statistical Analysis for Blacksburg's Filtered TI Data Set.

Blacksburg, VA				
Min	**Mean**	**Max**	**Median**	**SD**
30.2061047	42.6794025	63.7576713	41.4513336	7.86320045

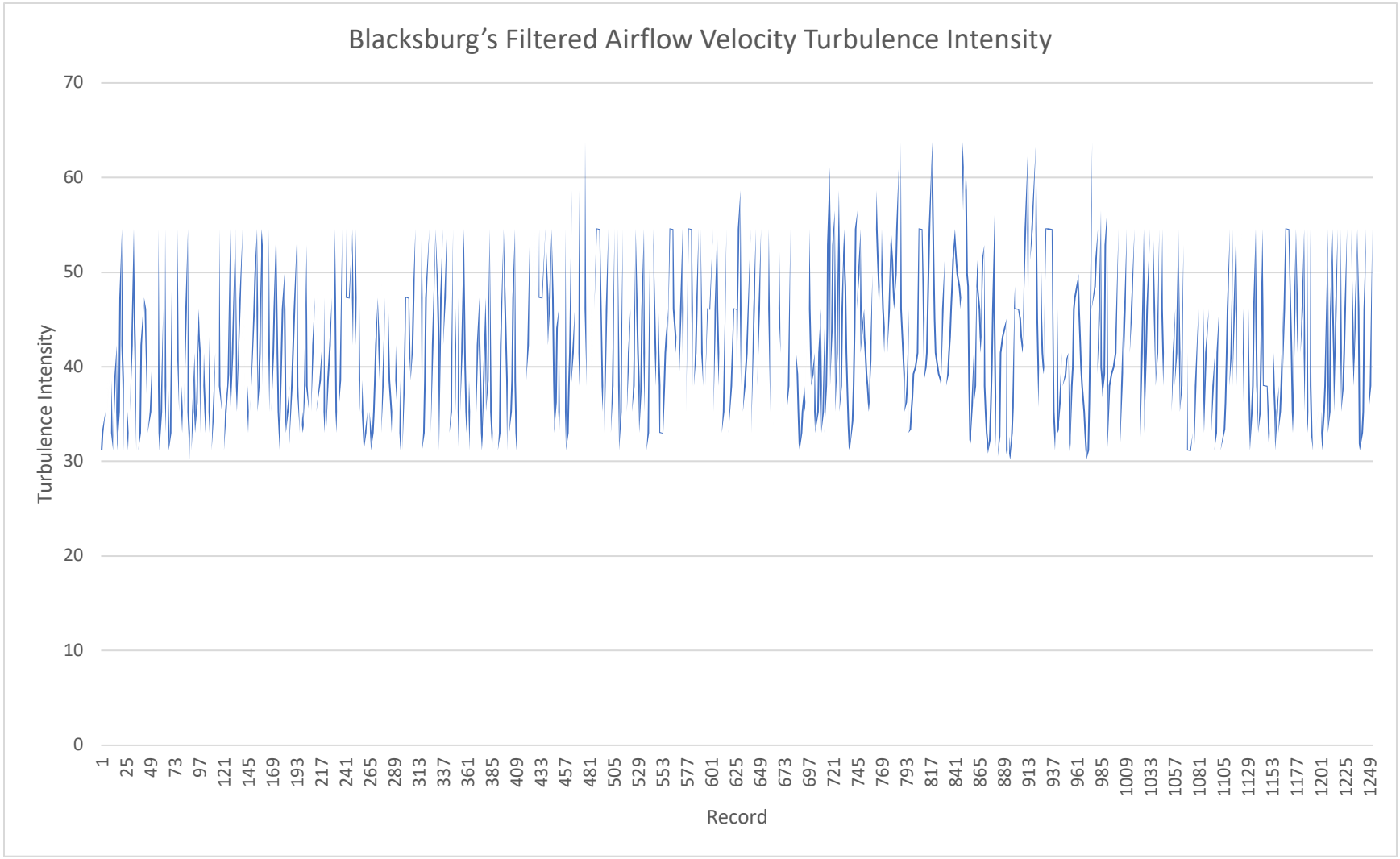

Figure 12: Blacksburg's Filtered Airflow Velocity Turbulence Intensity.

4.3. Summary

In summary, the focus of this phase of the research was on collecting and analyzing data regarding the natural airflow characteristics. The research involved exploring the applicability of various data sources, including literature, related standards, and simulation software data files, to determine the features of natural airflow.

Through literature review, the outdoor human comfortable airflow velocity was determined to be between 2.24 - 11.18 mph which is equal to 1 - 5 m/s. This finding became a pivotal reference in defining the acceptable range for natural airflow characteristics. ASHRAE standards such as Standard 55 were also considered, emphasizing their significance in evaluating human comfort satisfaction in indoor environments based on factors such as air temperature and air velocity. However, recognizing the limitations of these standards, particularly in the context of natural ventilation and the adaptive comfort model, the research proposed an extended temperature range of 68 - 83°F. This adjustment aimed to accommodate the subjective nature of comfort, considering individual factors that might affect it, and make the outdoor comfort airflow velocities acceptable in indoor environments.

The process of determining the climatological location of the study was then outlined, emphasizing the importance of selecting representative locations to capture diverse climatic conditions. Using the ASHRAE climate zones as a guide, Blacksburg, Virginia, Los Angeles, California, and initially, Honolulu, Hawaii, were chosen. The weather data sets for these locations were analyzed to assess their suitability for the study. Ultimately, Blacksburg emerged as the chosen location due to its larger and more variable natural airflow data set.

The data collection process involved extracting TMY files and filtering them based on the temperature and airflow velocity criteria. The filtered data set for Blacksburg underwent thorough statistical analysis, providing insights into the natural comfortable airflow velocity range, with a mean of 6.058 mph. The distribution pattern was visualized through normal distribution graphs, showcasing the majority of values within the natural comfort range.

The chapter concluded with an exploration of TI to understand the variability and fluctuations in natural airflow patterns at a smaller time scale. Blacksburg's hourly normal distribution and TI, when filtered for the natural comfort zone, were presented and served as a valuable component for comparison in the experimental study.

This chapter laid the groundwork by comprehensively collecting and analyzing data on natural airflow characteristics. The proposed extended temperature range, the careful selection of representative locations, and the detailed statistical analysis of Blacksburg's data set have set the stage for the experimental study, providing a robust foundation for further investigations into the dynamics of natural ventilation in indoor environments.

5.Chapter Five: Experiment Specifications and Assumptions

5.1. Mechanical Device Selection

To select the most suitable mechanical device that aligns with the research objectives, a thorough evaluation and comparison of alternative options were conducted. The assessment involved an analysis of the advantages associated with each mechanical device, focusing on key criteria. The process for determining these advantages and assigning importance values is mentioned below.

5.1.1. Criteria for Evaluation

5.1.1.1. Airflow Variability

The ability of each mechanical device to provide a wide range of airflow velocities was considered a crucial factor. Airflow variation is essential to mimic natural conditions, contributing to a more comprehensive development of indoor airflow dynamics.

5.1.1.2. Turbulence Intensity (TI)

TI plays a vital role in replicating the natural fluctuations of airflow. Mechanical devices capable of producing varying turbulence intensities were favored to simulate the dynamic nature of natural airflow patterns.

5.1.1.3. Device Height

The height of the mechanical device was considered as it influences the dispersion of airflow. A taller device contributes to a more effective airflow distribution pattern.

5.1.2. Determination of Advantages

5.1.2.1. Scoring System

Each criterion was assigned a numerical score representing its perceived advantage. The scoring system ranged from 1 (low advantage) to 5 (high advantage).

5.1.2.2. Importance Weighting

Importance values were assigned to each criterion to reflect its significance in meeting the research objectives. The importance scale ranged from 1 (low importance) to 3 (high importance).

5.1.2.3. Advantage Calculation

The advantage score for each criterion was calculated by multiplying the scoring and importance values. The cumulative advantage score for each mechanical device was then obtained by summing the scores across all criteria.

Table 9 presents the scoring process based on the specified criteria for the mechanical devices.

Table 9: Scoring Process Based on the Specified Criteria for the Mechanical Devices.

Criteria	Scoring (1-5)	Importance Weight (1-3)	Advantage Score
Airflow Variability	5	3	15
Turbulence Intensity	5	3	15
Device Height	3	2	6

Table 10 presents a comparison between the alternative mechanical devices, and Table 11 presents the scoring and evaluation for these options based on the advantage scores calculated in Table 9.

Table 10: Sample Comparison Between Different Types of Mechanical Devices (Amazon.com).

	NGT335	NGT425	NGT33DC	NGT42DC
Energy Smart Technology	No	No	Yes	Yes
Speed Settings	5	5	1 - 99	1 - 99
Max Distance	85 ft	100 ft	90 ft	100+ ft
Controls	Touch-Sensitive	Touch-Sensitive	Touch-Sensitive	Touch-Sensitive
Removable Grill	Yes	Yes	Yes	Yes
Weight	8.9 lbs.	10.2 lbs.	8.3 lbs.	9.6 lbs.
Dimensions (H*W*D) - Inches	32.3*11*11	42.3*13*13	32.3*11*11	42.3*13*13
Power Cord Length	6 ft.	6 ft.	7 ft.	7ft.
Volts - Hertz	120V / 60HZ	120V / 60HZ		

Table 11: The Scoring and Evaluation of the Alternative Mechanical Devices.

	NGT335	**NGT425**	**NGT33DC**	**NGT42DC**
Airflow Variability (out of 15)	1	1	15	15
Turbulence Intensity (out of 15)	1	1	15	15
Device Height (out of 6)	5	6	5	6
Total Advantage Score (out of 36)	7	8	35	36

Based on this, the Vornado NGT42DC was chosen because of its overall advantage score mainly resulting from the large variability in airflow velocity, the turbulence intensity, and device height.

5.1.3. Localized mechanical forced airflow system details

The Vornado NGT42DC energy smart tower circulator was chosen for this research. According to the manufacturer details, the NGT42DC tower circulator brings V-Flow air-circulating technology to the next level with Versa-Flow adjustable airflow plus an Energy Smart DC motor. Versa-Flow allows the user to create a wide range of airflow velocities and patterns. The constant airflow (over 100' throw) eliminates the need for oscillation because the high volume of air continuously moves throughout the room. The brushless DC motor pairs with 99 variable speeds for precise control. The NGT42DC has touch-capacitive controls, a 1–12-hour auto-off timer, an easy-to-clean air inlet grill, and remote control. Figure 13 presents the device.

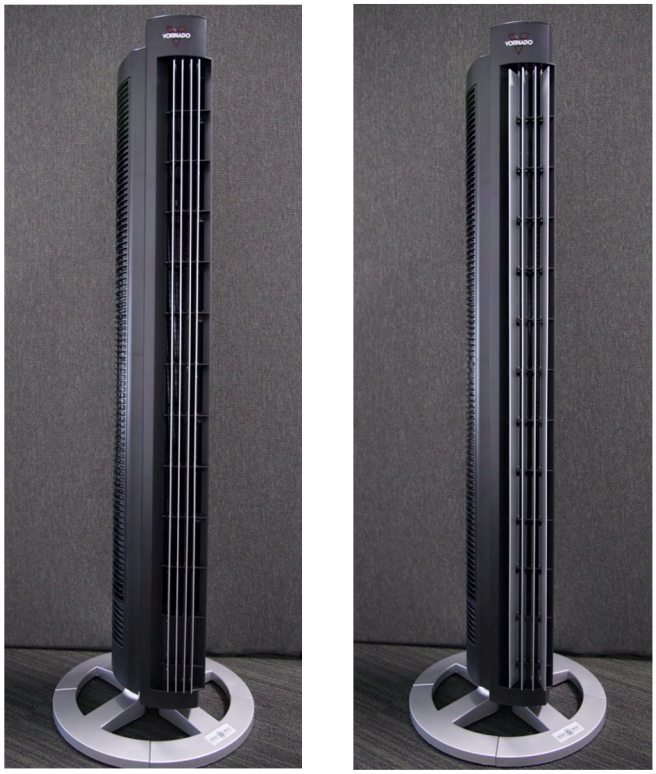

Figure 13: Vornado NGT42DC Energy Smart Tower Circulator with Options of 0 and 45-Degree Blades Angle.

Below are the key features and properties of the Vornado NGT42DC as provided by the manufacturer;

- CONTINUAL AIRFLOW – Utilizes Vornado's signature Versa-Flow Technology to provide complete circulation of all the air in a room. A unique crosscut outlet creates a wide span of constant airflow, eliminating the need for a wobbly oscillating base.

- MOVES AIR FURTHER – A powerful, energy-smart DC motor uses less energy but produces a higher volume of air movement and pushes air over 100 feet.
- ENERGY-SAVING TIMER – A 1–12-hour auto-off timer ensures the user runs the tower circulator in an efficient, energy-saving way.
- VARIABLE SPEED CONTROL – True variable speed control provides a nearly infinite amount of speed settings, allowing users to select their ideal atmosphere using touch-sensitive buttons. A remote control brings added convenience.
- SUPERIOR SUPPORT – Choosing a Vornado Energy Smart Fan means investing in superior performance and design that will deliver total satisfaction.
- Built to meet U. S. voltage requirements. Certified, safety-tested.

5.2. Research Workstation

In the pursuit of advancing the understanding and application of biophilic design principles within modular workstations, a partnership was established with Steelcase, a renowned leader in workplace solutions based in the United States. This collaboration sought to integrate nature-inspired elements into the work environment through the development of the BLNAS. As part of their commitment to supporting innovative research, Steelcase graciously provided the Flex Collection 120° Straight Height-Adjustable Desk (Model: FLXSWS3A1).

Steelcase has been at the forefront of workplace innovation for over a century, consistently pushing the boundaries of design and functionality. Their commitment to understanding the evolving nature of work and creating solutions that enhance productivity and well-being underscores their leadership in the industry.

Beyond innovation, Steelcase prioritizes sustainability in both their products and operations. The use of recyclable and environmentally friendly materials in the Flex Collection reflects their dedication to reducing the environmental impact of their products, contributing to a more sustainable and responsible future.

The collaboration with Steelcase was instrumental in meeting the research objectives. The FLXSWS3A1 workstation exemplifies Steelcase's commitment to fostering advancements in

workplace design and environmental responsibility. The invaluable support from Steelcase has enabled the development and implementation of the biophilic localized natural airflow simulator within a real-world, state-of-the-artwork setting. Below are some features of this workstation.

1. Design and Ergonomics

The FLXSWS3A1 exemplifies Steelcase's dedication to ergonomic design and workplace flexibility. The 120° configuration of the workstation encourages collaborative workspaces, fostering a sense of community and shared purpose among users. The height-adjustable feature ensures adaptability, accommodating individual preferences and promoting a dynamic and comfortable working experience.

2. Materials and Construction

Crafted with precision and durability in mind, the workstation boasts high-quality materials in its construction. Steelcase's commitment to sustainability is evident in the use of eco-friendly materials, aligning with the principles of a responsible and environmentally conscious workplace.

3. Technology Integration

The FLXSWS3A1 is equipped with cutting-edge technology to enhance the user experience. Features such as integrated cable management and compatibility with technology tools seamlessly integrate modern work requirements into the workstation. This technological integration aligns with the demands of contemporary work environments, emphasizing efficiency and connectivity.

Figure 14 presents some drawings for the 120° Straight Height-Adjustable Desk (Model: FLXSWS3A1) that was used in the research experiment and Figure 15 presents some photos for it.

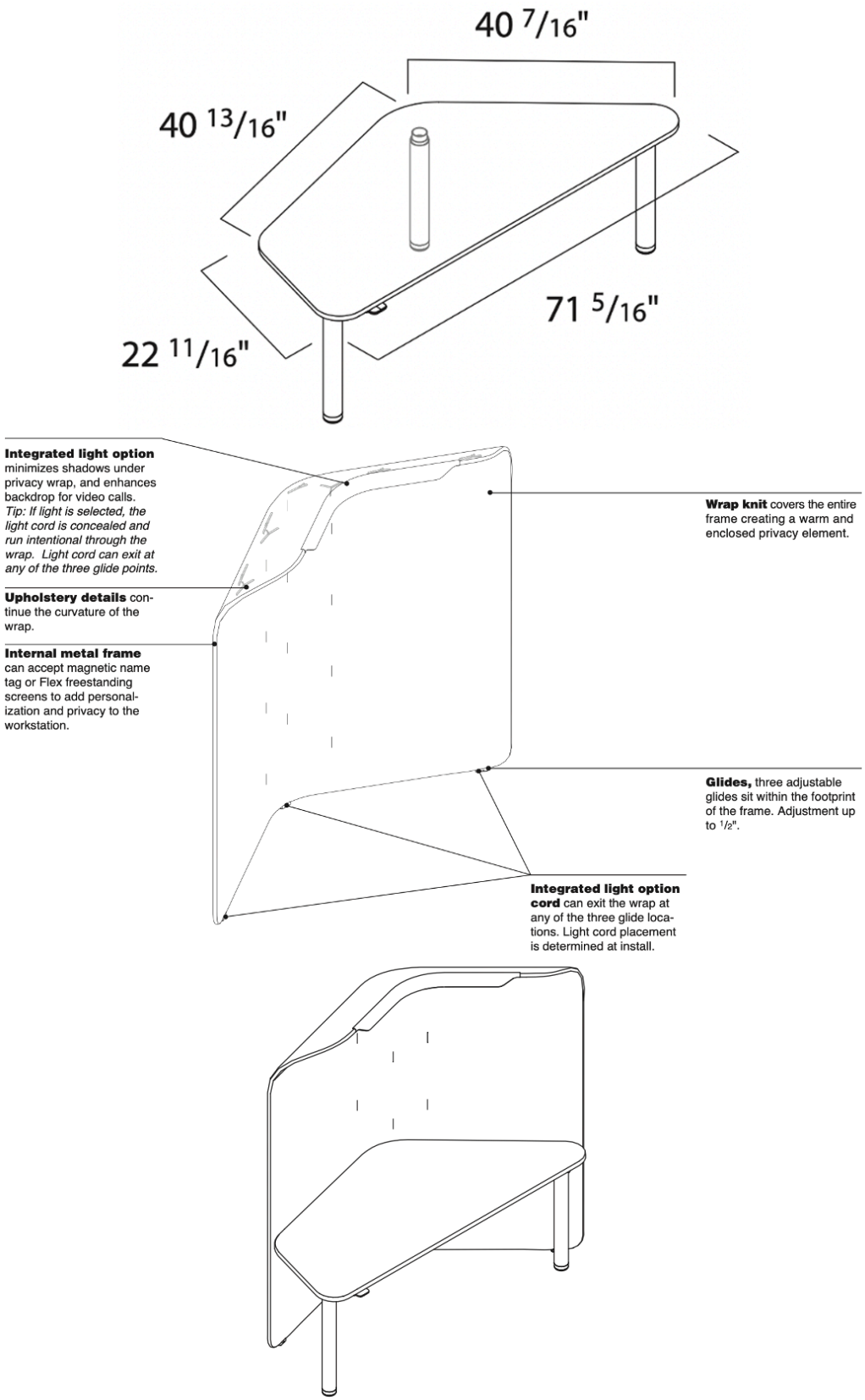

Figure 14: Drawings for the 120° Straight Height-Adjustable Desk and (Steelcase.com)

Figure 15: Photos for the 120° Straight Height-Adjustable Desk (Steelcase.com)

The inclusion of the Steelcase Flex Collection workstation in this research not only elevates the experimental setup but also signifies the collaboration between academia and industry. This partnership underscores the importance of integrating biophilic design principles into

contemporary workspaces, and the FLXSWS3A1 serves as a tangible embodiment of this shared vision.

5.3. Research Work Environment

The selection of an appropriate work environment was paramount in the development and testing of BLNAS. In pursuit of realistic and applicable results, the GFURR office was identified as an ideal location for the experiment. The GFURR office at Virginia Tech, primarily occupied by Ph.D. architectural students, is located at Washington St SW, Blacksburg, VA 24060. The office was chosen for several reasons:

1. Realism and Applicability

The GFURR office serves as an authentic representation of a contemporary and dynamic workspace. As a hub for doctoral students in architecture, the office environment reflects the diverse and collaborative nature of modern research spaces.

2. Suitability for Experimentation

The suitability of the GFURR office for experimentation is paramount to the success of the BLNAS experiment. The office's layout and design have been meticulously chosen to seamlessly align with the objectives of the research. With its array of modular workstations, collaborative zones, and individual workspaces, the GFURR office provides an ideal environment for rigorously testing the effectiveness of the airflow simulator. This deliberate selection increases the reliability of the research and ensures that the results are not only academically sound but also directly applicable to office settings, enhancing the practical relevance of the study.

3. Accessibility and Collaboration

The strategic location of the GFURR office on Washington St SW in Blacksburg, VA, holds significant importance for the future phases of this research. As the experiment advances to include participant evaluations of the BLNAS impact on occupants' health, wellness, and well-being, the accessibility of the GFURR office becomes a crucial factor. Its proximity to Virginia Tech's campus not only facilitates easy access for both researchers and participants but also

streamlines collaboration within the academic community. This accessibility ensures a seamless and efficient participation process for both participants and researchers, laying the foundation for a more inclusive and comprehensive assessment of the BLNAS's effects on the occupants' overall experience in the workspace.

Figure 16 presents a partial plan of the GFURR office and Figure 17 presents the location of the workstation and the experiment within the office.

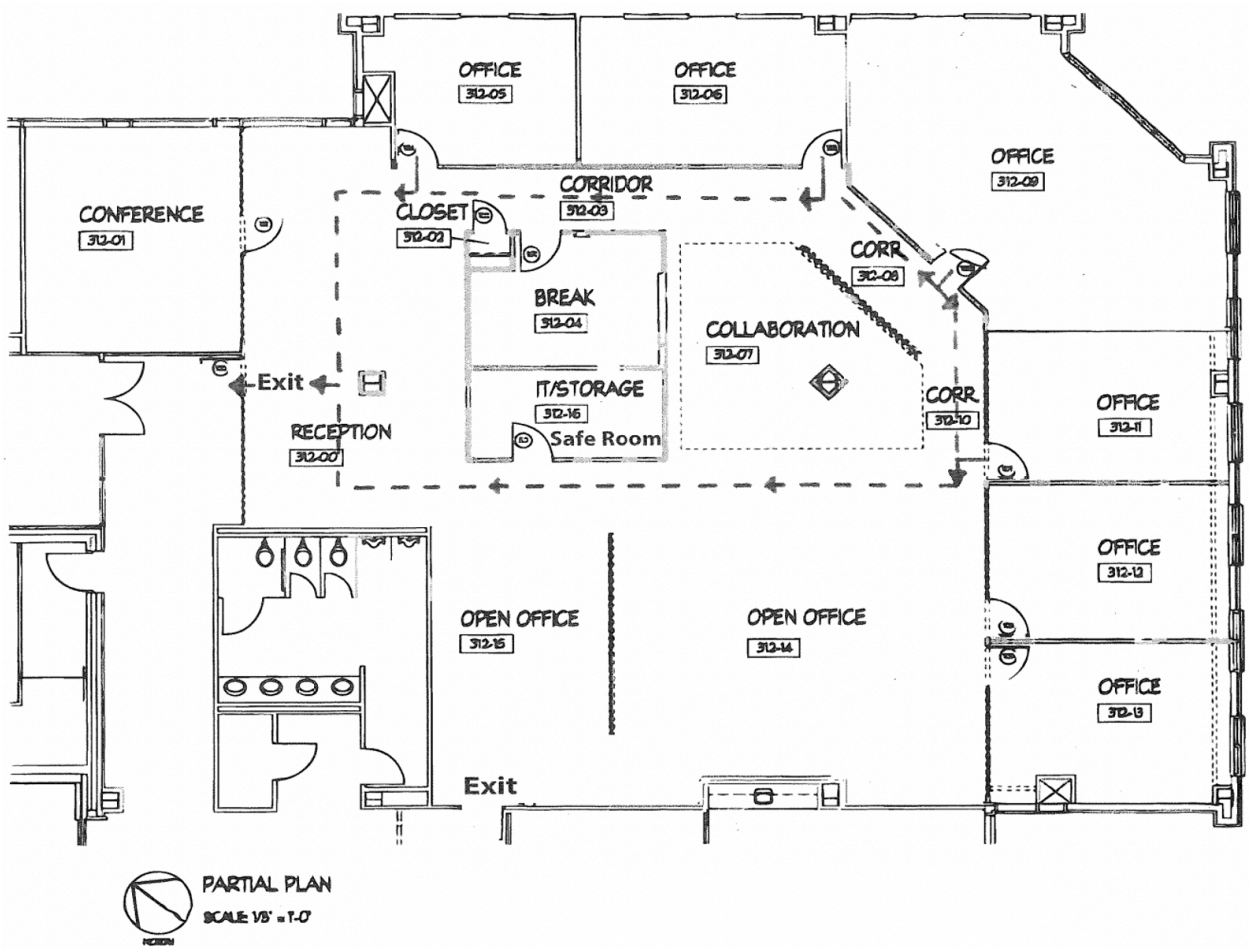

Figure 16: Partial Plan of GFURR Office.

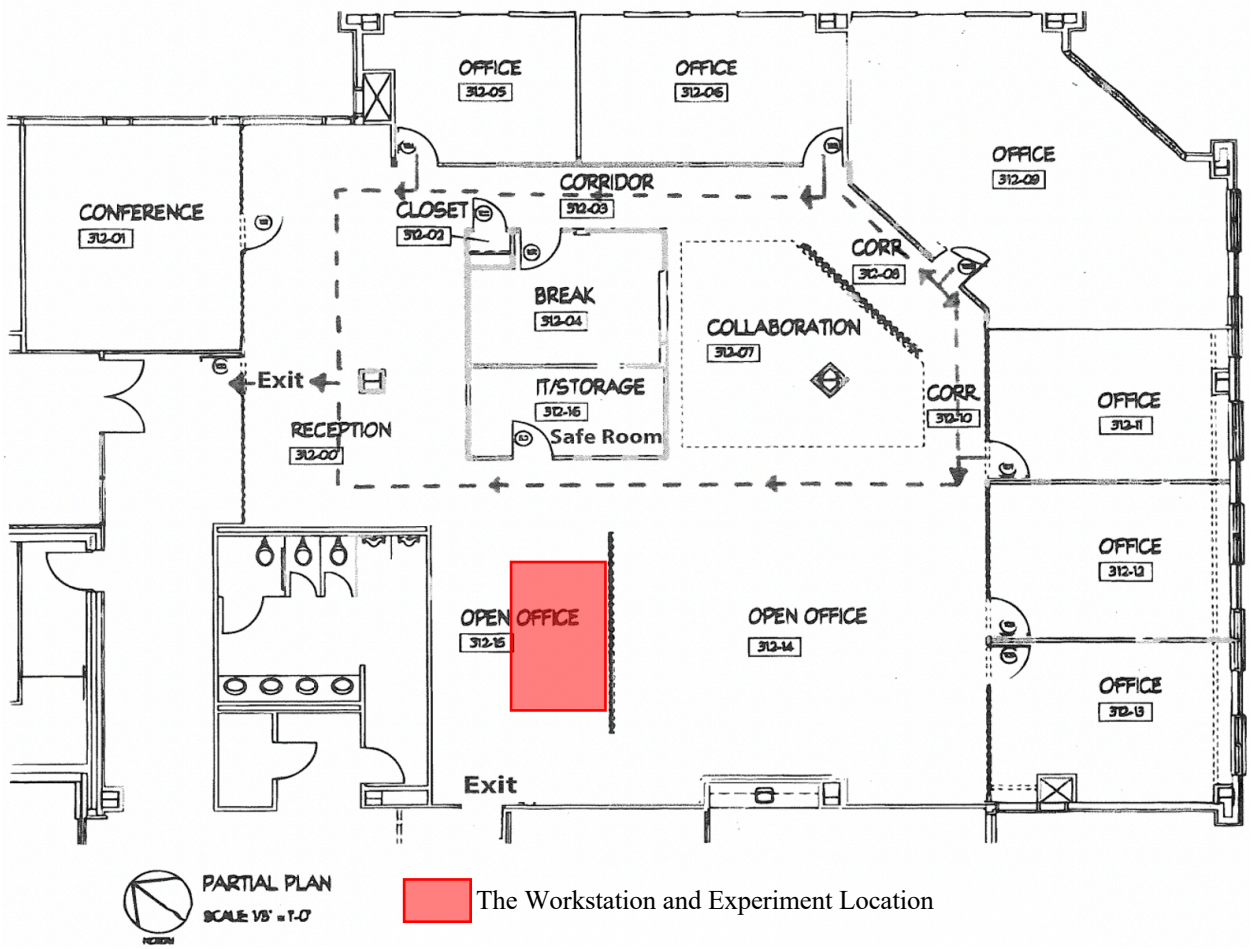

Figure 17: The Workstation and Experiment Location within GFURR Office.

5.4. Datalogger

Accurate and reliable data collection is fundamental to the success of any research endeavor, especially in the development of a BLNAS. For this purpose, the research utilized the Campbell Scientific CR1000X datalogger, a sophisticated instrument designed to capture and store data with precision. The Campbell Scientific CR1000X is a versatile and advanced datalogger renowned for its robust capabilities in environmental monitoring and data acquisition. It features a compact design, making it suitable for various applications, including the intricate requirements of the BLNAS. CR1000X characterized by several features such as;

1. Versatility: The CR1000X is equipped to handle a diverse range of sensors and measurement devices, providing flexibility in capturing different types of environmental data.

2. High-Speed Data Logging: With a high-speed analog measurement capability, the CR1000X ensures the capture of data at precise intervals, allowing for a detailed analysis of airflow patterns and environmental conditions.
3. Storage Capacity: The datalogger is equipped with ample storage capacity, enabling the continuous recording of data over extended periods, essential for capturing variations in airflow and environmental parameters.
4. Compatibility: Its compatibility with various sensors and input devices allows seamless integration into the BLNAS experiment setup, ensuring comprehensive data collection.

The CR1000X played a central role in the data acquisition process for the BLNAS experiment. Its primary functions included:

1. Real-time Monitoring: The datalogger facilitated real-time monitoring for the airflow velocity, providing a continuous stream of data for analysis.
2. Data Synchronization: Integration with the sensor's components allowed the CR1000X to synchronize data collection with the operation of the mechanical device, ensuring that the captured data corresponded accurately to the sensor's performance.
3. Precision in Measurements: The high precision of the CR1000X ensured that the collected data reflected the subtle nuances in airflow patterns, contributing to a nuanced understanding of the simulator's impact on the workspace environment.

Figure 18 presents the Campbell Scientific CR1000X from the front angle view and Figure 19 presents an explanation of the wiring panel and terminal functions for the CR1000X too.

Figure 18: CR1000X Front Angle View (campbellsci.com).

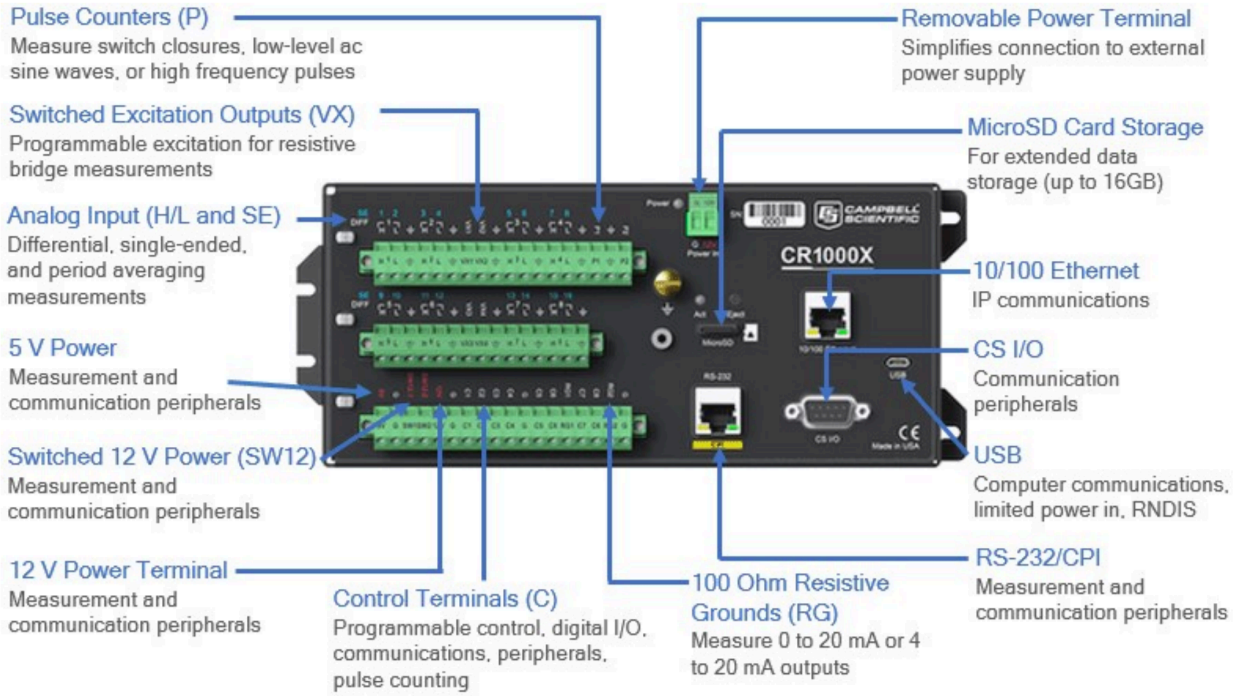

Figure 19: CR1000X Wiring Panel and Terminal Functions (campbellsci.com).

Besides the datalogger, selecting the right software for data logging and management is crucial in ensuring the success of any research project. In the case of the CR1000X datalogger, several options are available each with its unique features such as; PC200W, PC400, LoggerNet,

etc. For this research, LoggerNet was chosen as the primary software for data collection, recording, and analysis.

LoggerNet is a robust data management software developed by Campbell Scientific, tailored for their dataloggers, including the CR1000X. It offers a comprehensive suite of tools for configuring, programming, and retrieving data from the datalogger, making it an invaluable asset in research settings.

LoggerNet was chosen for several reasons including;

1. Reliability and Accuracy: LoggerNet is known for its reliability and accuracy in handling data from Campbell Scientific dataloggers. By choosing LoggerNet, the research project aims to uphold the highest standards of data accuracy, essential for drawing meaningful conclusions from the experiment.
2. User-Friendly Interface: The user-friendly interface of LoggerNet makes it accessible to researchers with varying levels of technical expertise. Its intuitive design enhances the efficiency of data management tasks, allowing researchers to focus more on the research itself rather than navigating complex software.
3. Technical Support and Updates: LoggerNet benefits from continuous technical support and updates from Campbell Scientific, ensuring that the software remains current and responsive to emerging research needs. This ongoing support enhances the overall stability and functionality of the data logging process.
4. Seamless Configuration and Programming: LoggerNet streamlines the configuration and programming of the CR1000X datalogger. Its user-friendly interface simplifies the process of setting up the logger to capture specific parameters, ensuring that the device operates in alignment with the research objectives.
5. Real-time Data Retrieval: One of the key advantages of LoggerNet is its ability to provide real-time access to data collected by the CR1000X. This feature is instrumental in monitoring the ongoing experiment, allowing researchers to make timely adjustments and ensuring that the data collected is both accurate and current.
6. Data Management and Storage: LoggerNet facilitates efficient data management and storage. It organizes and archives data collected by the CR1000X, ensuring that

researchers have a systematic and accessible database for post-experiment analysis and interpretation.

7. Compatibility and Integration: The choice of LoggerNet is motivated by its seamless compatibility with the CR1000X and other Campbell Scientific dataloggers. This integration ensures optimal performance and reliability, minimizing the risk of data loss or misinterpretation.

Figure 20 presents the LoggerNet, datalogger support software, interface and data analysis.

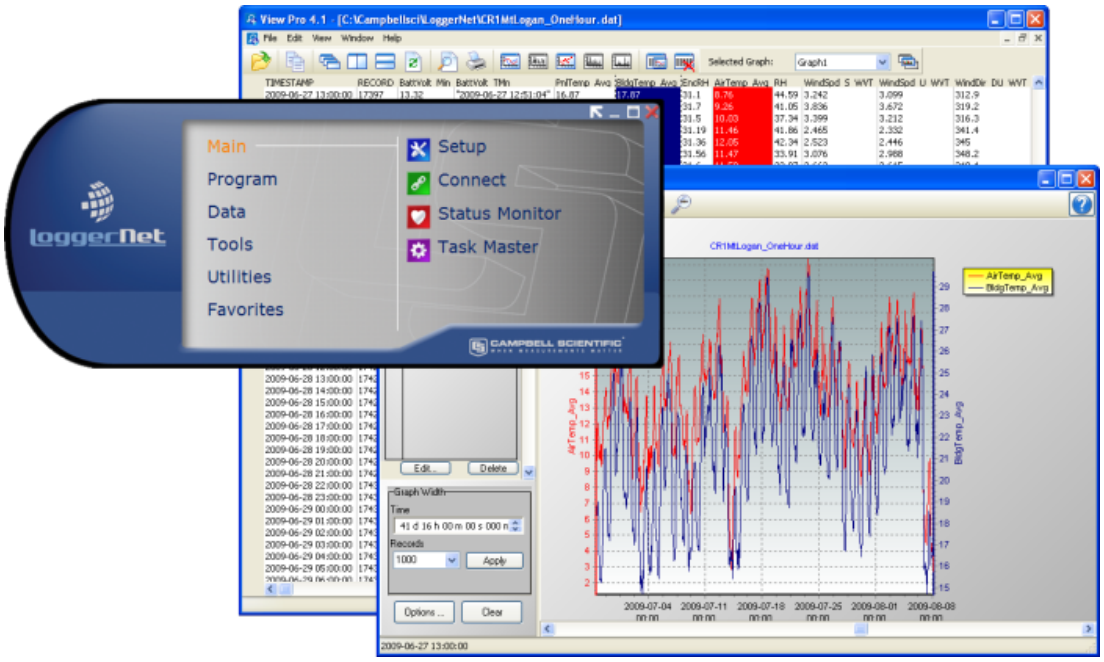

Figure 20: LoggerNet, Datalogger Support Software, Interface and Data Analysis (campbellsci.com).

5.5. TSI Air Velocity Transducer

Accurate measurement of airflow velocity is a critical component in understanding the dynamics of the BLNAS. To capture precise data at the seated location for the occupant and analyze the impact of the BLNAS, a TSI Air Velocity Transducer Model 8465 was employed as a sensor. The TSI Air Velocity Transducer Model 8465 is a state-of-the-art instrument designed for the accurate measurement of air velocity in various environments. Its compact design, high sensitivity, and reliability make it an ideal choice for applications where detailed airflow analysis

is crucial. The Model 8465 is equipped with features that enhance its suitability for experimental settings, ensuring precision in capturing airflow data. Below are some of these features.

1. High Sensitivity: The transducer's high sensitivity allows for the measurement of subtle changes in airflow velocity, providing a detailed understanding of the airflow patterns.
2. Compact Design: With a compact and unobtrusive design, the Model 8465 is well-suited for use in occupied spaces, enabling unobtrusive placement at occupant's seating and within the GFURR work area for realistic data collection.
3. Real-time Monitoring: The transducer facilitates real-time monitoring of airflow velocity, allowing for dynamic adjustments and observations during the operation of the biophilic localized natural airflow simulator.
4. Compatibility: Its compatibility with data logging systems, including the CR1000X, ensures seamless integration into the overall data acquisition setup.

The TSI Air Velocity Transducer Model 8465 played a pivotal role in the experiment, contributing to a comprehensive understanding of airflow dynamics at the measurement location. Its functions within the research included:

1. Precise Velocity Measurement: Placed strategically at the occupant location, the transducer captured precise airflow velocity data, allowing for the assessment of the simulator's impact on localized air circulation.
2. Occupant Comfort Analysis: By focusing on the occupant's seated location, the transducer provided valuable insights into the comfort levels experienced by individuals in the workspace, influenced by the localized natural airflow created by the simulator.
3. Correlation with Simulator Operation: The transducer's real-time monitoring capabilities ensured that the captured velocity data correlated directly with the operation of the BLNAS, facilitating a nuanced analysis of cause-and-effect relationships.

The integration of the TSI Air Velocity Transducer Model 8465 into the experimental setup was instrumental in elevating the precision and reliability of the research outcomes. Its ability to capture detailed airflow velocity data at the occupant location contributes significantly to the overarching goal of enhancing biophilic design principles in contemporary workspaces. Figure 21 presents the TSI Air Velocity Transducer Model 8465 that was used in this research. Figure 22 presents the TSI Air Velocity Transducer Model 8465 inside enclosure.

Figure 21: TSI Air Velocity Transducer Model 8465 (tsi.com).

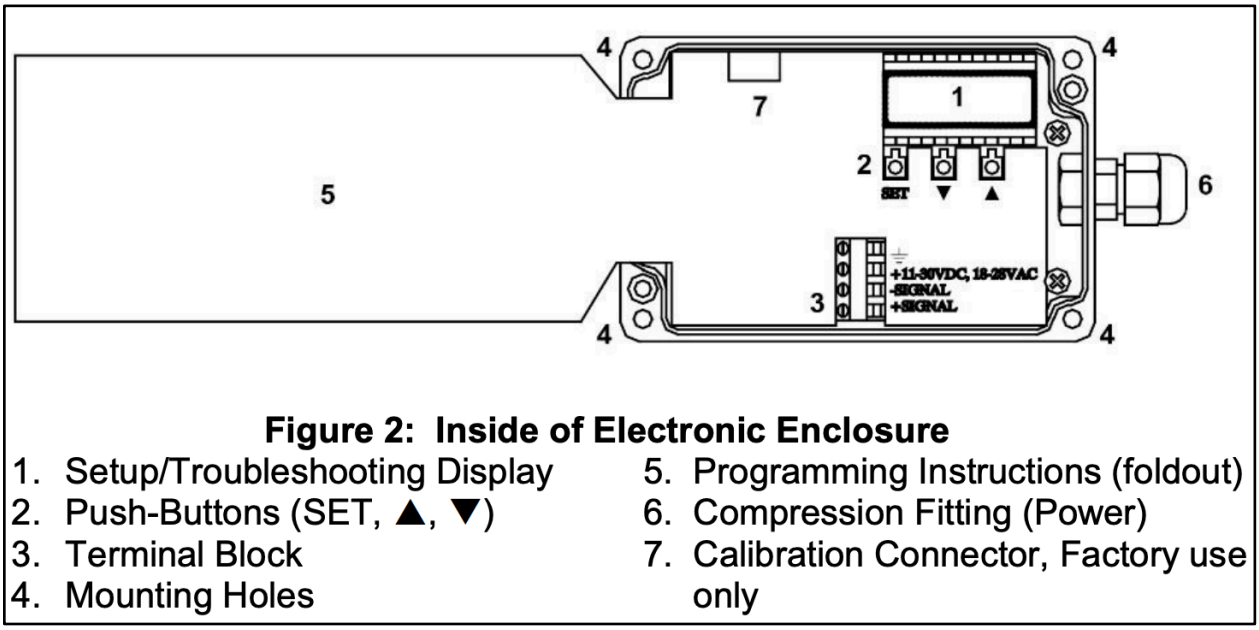

Figure 2: Inside of Electronic Enclosure

1. Setup/Troubleshooting Display
2. Push-Buttons (SET, ▲, ▼)
3. Terminal Block
4. Mounting Holes
5. Programming Instructions (foldout)
6. Compression Fitting (Power)
7. Calibration Connector, Factory use only

Figure 22: TSI Air Velocity Transducer Model 8465 Inside Enclosure (tsi.com).

5.6. Experiment Setup and Documentation

The successful execution of the BLNAS experiment hinged on a meticulously planned and executed setup process. This section provides a detailed account of the step-by-step procedures

that were applied, including assembling the workstation, configuring the datalogger, and connecting the TSI Air Velocity Transducer Model 8465.

5.6.1. Assembling the Workstation

The initial phase of the experiment involved the assembly of the designated Steelcase Company workstation within the GFURR office at Virginia Tech. Careful attention was paid to having a realistic office environment, comprising modular workstations, collaborative zones, and individual workspaces. Figure 23 presents the process of assembling the workstation and the final result.

Figure 23: The Process of Assembling the Workstation and the Final Result.

5.6.2. Configuring Datalogger with LoggerNet

Following the workstation assembly, the CR1000X datalogger was integrated into the setup. LoggerNet, a robust data management software, was downloaded and configured to work seamlessly with the CR1000X. This step was crucial in ensuring real-time data retrieval, efficient data management, and compatibility with the upcoming sensor integration. Figure 24 presents the process of configuring the datalogger with the LoggerNet software.

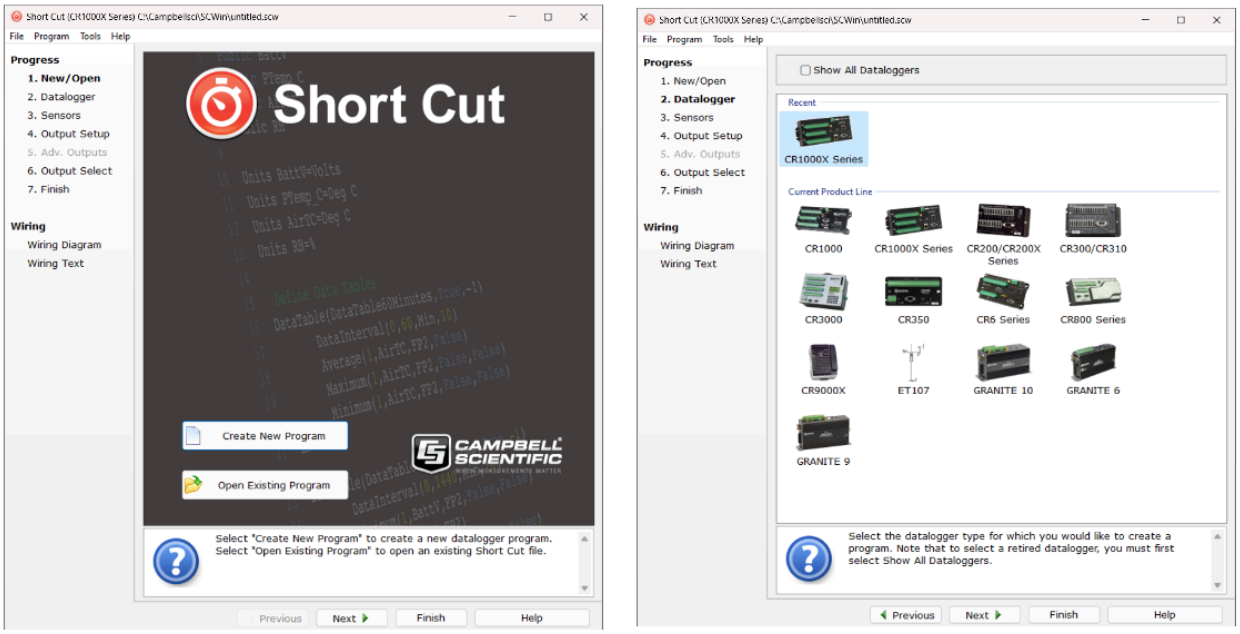

Figure 24: The Process of Configuration of the Datalogger with the LoggerNet Software.

5.6.3. Powering the Datalogger and the Sensor

To guarantee the operation of the devices and the continuous and reliable data acquisition process, the CH100, from Campbell Scientific Company, was chosen as the power source for both the CR1000X datalogger and the TSI Air Velocity Transducer Model 8465. This power source provided the necessary energy to sustain the experiment throughout its duration. It provided the devices with a continuous current of 12V. Figure 25 presents the CH100 power source used in this experiment.

Figure 25: Campbell Scientific CH100 Power Source Supply.

5.6.4. Connecting the Datalogger with the TSI Air Velocity Transducer

The TSI Air Velocity Transducer Model 8465, a key component for capturing airflow velocity data, was then connected to the CR1000X datalogger. The use of 18AWG cables ensured a secure and efficient connection between the datalogger and the sensor. Four ports were strategically utilized to establish a reliable and stable link between the two devices. The connection between the devices was created as below and Figure 26 presents the connection created between the CR1000X and the sensor TSI 8465.

1. The **(+)** signal port at the sensor was connected with the **(H1)** port at the datalogger.
2. The **(-)** signal port at the sensor was connected with the **(L1)** port at the datalogger.
3. The **(11-30 VDC or 18-28 VAC)** port at the sensor was connected with the **(12V)** port at the datalogger.
4. The **(ground)** port at the sensor was connected with the **(G)** port at the datalogger.

Figure 26: The Connections Created between the Datalogger CR1000X and the Sensor TSI 8465.

5.6.5. Sensor's Programming and LoggerNet Integration

LoggerNet provides the users with several ready programs suitable to be used directly based on the used sensor. In the context of the TSI Air Velocity Transducer Model 8465, utilizing pre-existing programs provided by LoggerNet was not feasible. This limitation arose from the absence of the TSI sensor in the Campbell Scientific sensors' list. However, LoggerNet offers a powerful alternative through CRBasic, allowing the creation of a custom program tailored to the specific sensor requirements.

To facilitate the integration of the TSI Air Velocity Transducer, a CRBasic program was written from scratch. This programming initiative aimed to establish a systematic recording of airflow velocity measurements at 10-second intervals, aligning the sensor's functionality with the objectives of the experiment. Figure 27 presents the CRBasic code written for this purpose.

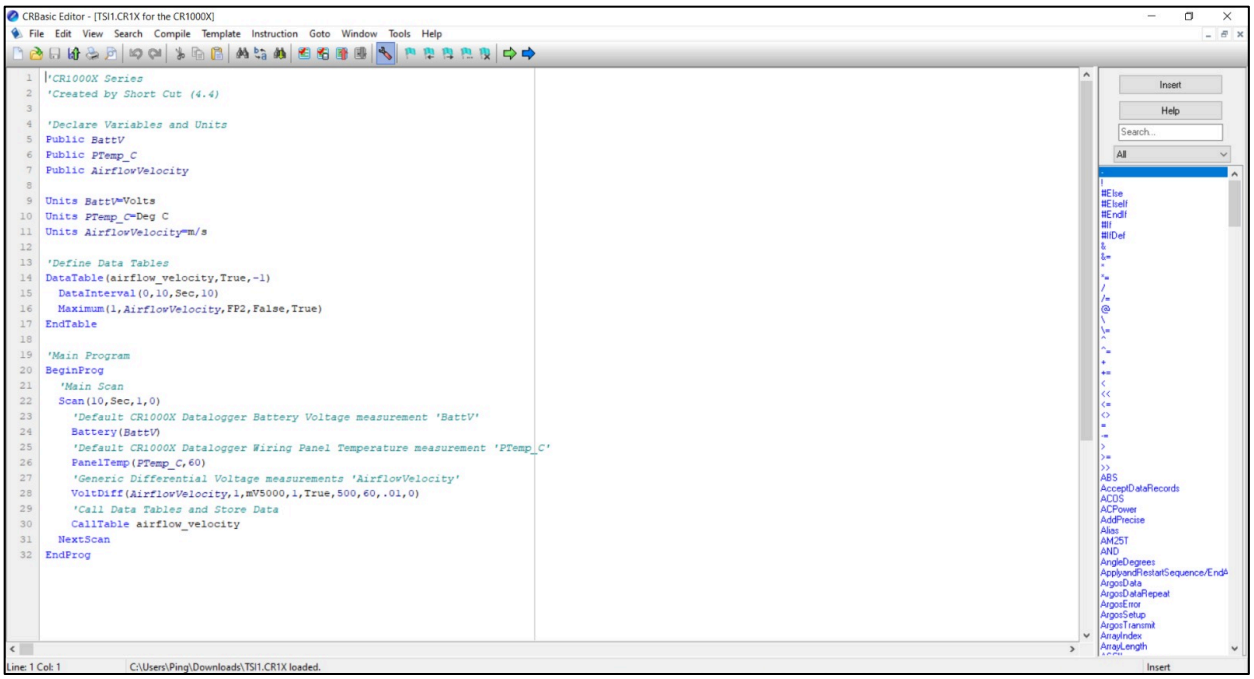

Figure 27: The CRBasic Code utilized for programming the TSI Air Velocity Transducer Model 8465.

The methodology of the TSI sensor involves measuring the voltage difference between positive and negative signals to determine the airflow velocity. To harmonize this process with LoggerNet, the sensor and its corresponding CRBasic code were seamlessly incorporated into the LoggerNet sensors' list under the generic measurements category, specifically as a differential voltage sensor. Figure 28 represents the steps involved in adding the TSI Air Velocity Transducer programming and integrating it into LoggerNet.

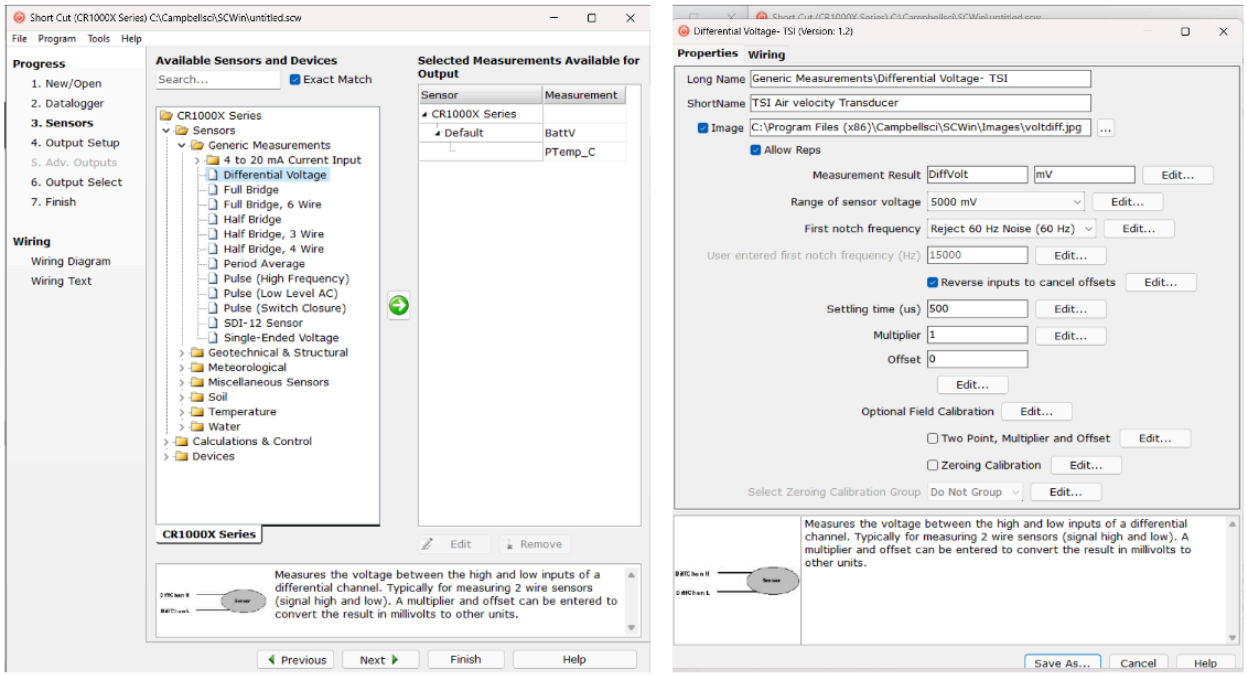

Figure 28: TSI Air Velocity Transducer Programming and LoggerNet Integration.

5.6.6. Setting Up the Sensor for Experimentation

This step involved fine-tuning the settings of the TSI Air Velocity Transducer to align with the specifics of the experiment. Calibration and configuration parameters were adjusted to guarantee the accuracy and reliability of the airflow velocity data collected during the BLNAS experiment. For that, setting up the sensor followed the next steps and Figure 29 presents the process of setting up the TSI Air Velocity Transducer.

1. SELECT UNITS = METERS (m/s)
2. SELECT FULL SCALE = FULL SCALE
3. SELECT OUTPUTS = 0 – 5 V
4. SELECT tc = 10.00

Figure 29: The process of Setting Up the TSI Air Velocity Transducer.

5.6.7. Setting Up the Sensor and the Mannequin (Test Dummy)

The final step was to fix the sensor at the location of a seated occupant. In simulating real-world conditions for the BLNAS experiment, a test dummy, or mannequin, was employed to represent the seated occupant. This intentional choice aimed to accurately replicate human presence and interactions within the workstation. The mannequin, strategically positioned at the workstation, provided a standardized point of reference for assessing the impact of the airflow simulator on occupant comfort and experience. It was positioned exactly at the middle of

occupant's side and 70 cm away from the mechanical device. Figure 30 presents the mannequin positioning.

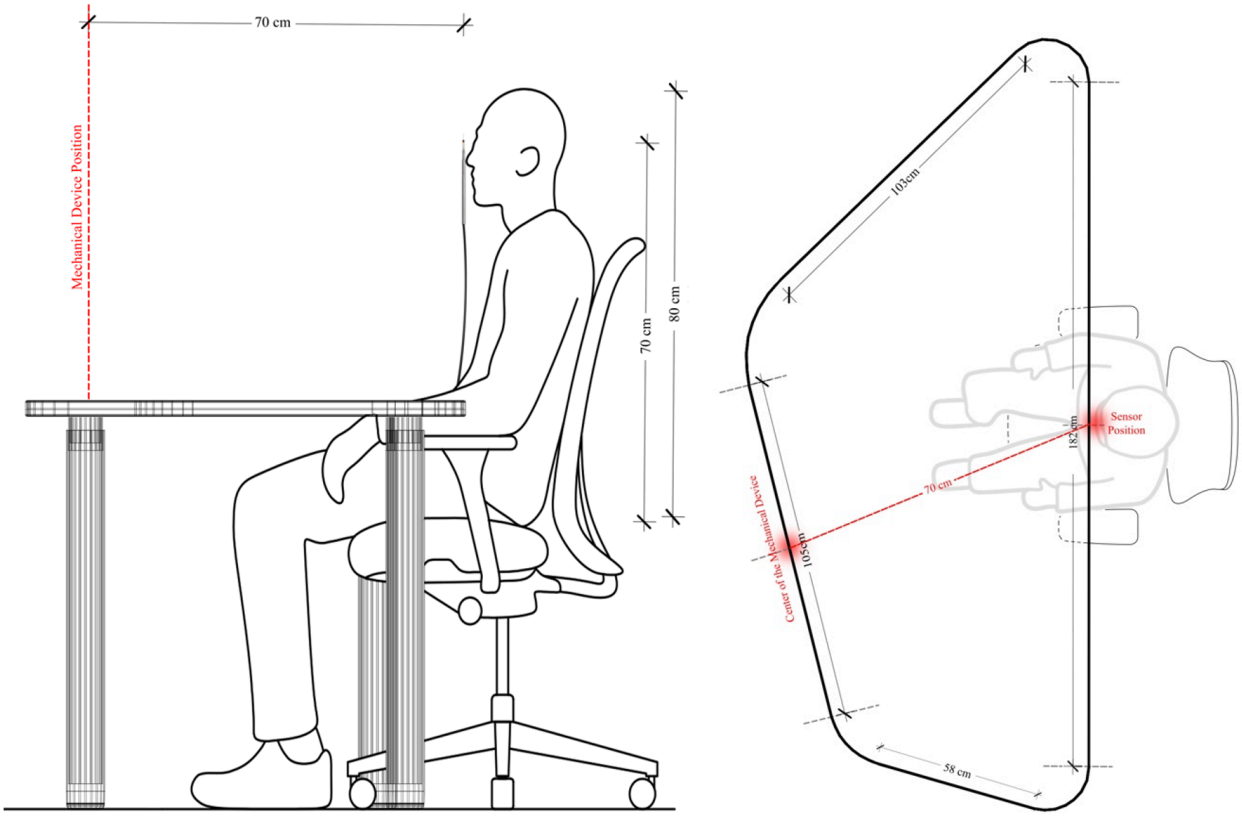

Figure 30: The Mannequin Positioning

To capture precise airflow velocity data, the TSI Air Velocity Transducer Model 8465 was strategically fixed near the mannequin's face. The sensor was positioned between the forehead, cheeks, and nose where the most important thermosensors for humans are found. Figure 31 presents the thermal receptors distribution on the human face. It was meticulously placed to mirror the conditions experienced by an actual occupant. This specific placement aimed to capture airflow patterns in areas most relevant to the occupant's thermal comfort and overall well-being.

The researcher acknowledges the discomfort potential of directing airflow towards the face, considering the natural airflow experienced on other body parts. However, targeting the forehead, rich in primary thermal sensors, is crucial for precise measurement. Later on, this discomfort might be solved by allowing users to customize airflow direction or by expanding coverage to other body areas.

Figure 31: The Thermal Receptors Distribution on the Human Face.

The mannequin, acting as a surrogate for the seated occupant, allowed for consistent and repeatable experimentation, ensuring that the effects of the airflow simulator were evaluated under standardized conditions. This setup provided a controlled environment for studying the localized impact of the simulator on the immediate surroundings of the occupant. Figure 32 presents the mannequin and sensor setup.

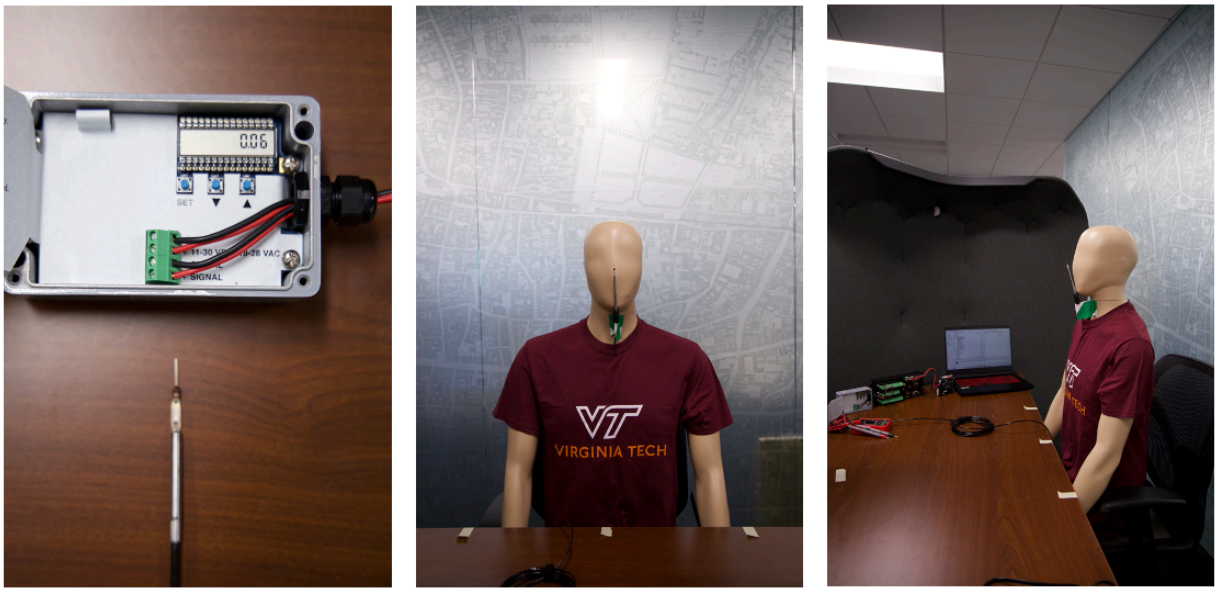

Figure 32: The Mannequin and Sensor Setup.

This deliberate integration of a mannequin into the experiment setup enhances the reliability and repeatability of the research outcomes. It not only serves as a surrogate for the occupant but also allows for a focused assessment of the airflow simulator's influence on key areas associated with thermal perception. The thoughtful placement of the sensor on the mannequin's face adds a layer of specificity to the experiment, capturing data in regions crucial to understanding the localized effects on occupant comfort.

In summary, the experiment setup process encompassed assembling the realistic workstation provided by Steelcase Company, configuring the CR1000X datalogger with LoggerNet, powering the devices with the CH100 power source, establishing a secure connection between the datalogger and the TSI Air Velocity Transducer, programming the sensor, integrating it into LoggerNet, and setting up the sensor for optimal experimentation. The documented setup process, supported by accompanying photos, serves as a comprehensive record of the experiment's physical implementation and ensures the reproducibility and reliability of the research outcomes. Figure 33 presents the full experiment setup.

Figure 33: The Full Experiment Setup.

5.7. Conclusion of the Experimental Test Setup

5.7.1. Research Variables

Based on the literature and collected data for this research, the main research variables were classified into three main categories as presented in Table 11:

1. **Indigenous Dependent Variables:** the main parameters that affect the users and their feelings about the natural airflow. These variables are:

1.1) Airflow velocity at the occupant's location.

1.2) Turbulence intensity at the occupant's location.

Those two variables were measured at the location of the occupant because they were determined to be the most influential variables associated with the natural airflow, and they were used to determine if the BLNAS creates the desired natural airflow patterns or not.

2. **Indigenous Independent Variables:** the selected airflow device (prototype) variables which impact the airflow and the user's feelings about it. These variables are:

2.1) Distribution (diffuser design)

A diffuser was designed and positioned in front of the airflow mechanism to help in distributing the airflow and achieving the natural airflow pattern. It is important to consider the diffuser as an independent variable because different outlet design characteristics might create different air distribution patterns. So, it was important to analyze different designs and evaluate their results to find the best design that produced the desired natural airflow patterns. For that, and for the purpose of this research, circular, vertical, and horizontal diffusers were observed and compared. Those three options might offer the most flexibility in terms of airflow and air pressure. More details about the diffusers and their designs are presented in section 5.7.3. Those options would allow the air to be distributed evenly across the workstation so the occupant could feel the airflow throughout the workstation. They might allow for smooth air distribution without consuming more energy to push the air through the diffuser. Additionally, these options were

thought to be easier to install and incorporate within the workstation as they require fewer components than other types of distribution systems.

2.2) Airflow velocity

A key variable was the airflow velocity where the objective was to simulate natural airflow velocities. For that, the air speeds were measured to determine the correlation with the target natural airflow velocities and those created by the BLNAS at the occupant location.

2.3) Airflow direction

Direction is another important variable for natural airflow. Direction was considered an independent variable because of its potential impact on the measured values of airflow velocity and turbulence intensity at the occupant location. For this research, three directions were employed, direct, downward, and upward. The location and orientation of the prototype determined the airflow direction. For the direct direction, the prototype was placed vertically at the center of the station. On the other hand, the prototype was positioned horizontally in the upward and downward directions. The mechanical device was positioned with the diffusers at the top for the downward airflow direction and at the bottom for the upward airflow direction. Figure 34 presents an illustration of the direction and location of the prototype and the outlet design.

It's important to mention that, developing the BLNAS was an iterative process where these suggested variables and cases were developed through the experiment and based on the results.

3. **Exogenous variables:** the variables that remained constant during the research were:

3.1) Mechanical Device Location (prototype).

It represents the prototype's location relative to occupant's seat. Regardless of the position and orientation of the prototype, the distance between it and the seated occupant was fixed to be 70 cm.

3.2) Study location (Blacksburg, Virginia).

The choice of study location, specifically Blacksburg, Virginia, serves as an exogenous variable in this study. This was important to determine the natural airflow features that were used

as a reference in the experiment. As discussed and presented in section 4.2, choosing the study location went through a well-designed process to reduce bias and establish a starting point for this research and other future research.

3.3) Natural airflow velocities.

The natural airflow velocities were also determined as an exogenous variable in this study. This variable refers to Blacksburg's filtered natural airflow data set that was developed and extracted in section 4.2.2 and was used later to evaluate the performance of the developed scenarios and their relativity to mimic the natural airflow patterns.

3.4) Natural airflow turbulence intensity.

The natural airflow TI was defined as an exogenous variable in this study. This variable refers to Blacksburg's filtered natural airflow TI that was generated in section 4.2.2 and was used later to evaluate the performance of the developed prototype scenarios and their relativity to mimic the natural airflow TI patterns.

To understand these variables, their relationships, and their impact on the resulting airflow variability Table 12 presents the intersection between the variables, and the resulting research cases.

Table 12: Research Variables (Illustrated by the Author).

	Research Variables		**Variable Type**
Experiment Environment	Study Location		Exogenous
Personalized Ventilation Unit (Prototype)	Distribution (Diffuser Design)	Circular	Indigenous Independent
		Vertical	
		Horizontal	
	Airflow Velocity	Natural Airflow Velocities	Indigenous Independent
	Mechanical Device Location (Prototype)		Exogenous
	Airflow Direction	Directed	Indigenous

		Downward	Independent
		Upward	
Natural Airflow	Velocity		Exogenous
	Turbulence Intensity		Exogenous
User	User's Turbulence Intensity		Indigenous Dependent
	User's Airflow Velocity		Indigenous Dependent

5.7.2. Research Cases

Based on research variables, Table 13 presents the intersection between research variables and the resulting research cases. Table 13 shows three main independent variables which are airflow velocity, airflow direction, and diffuser design, and their sub-variables, intersected with each other to generate the research cases. In the end, the intersection results in 9 cases that need to be evaluated to find if any of them might simulate natural airflow patterns.

Table 13: Intersection Between Research Variables, and the Resulting Research Cases.

		Airflow Velocity		
		Natural Airflow Velocities		
	Airflow Direction	*Direct*	*Downward*	*Upward*
Diffuser Design	*Circular*	Case #1	Case #2	Case #3
	Vertical	Case #4	Case #5	Case #6
	Horizontal	Case #7	Case #8	Case #9

To further illustrate the research cases, Figure 34 shows an illustration of the variables and their relationship with each other and the resulting experimental cases.

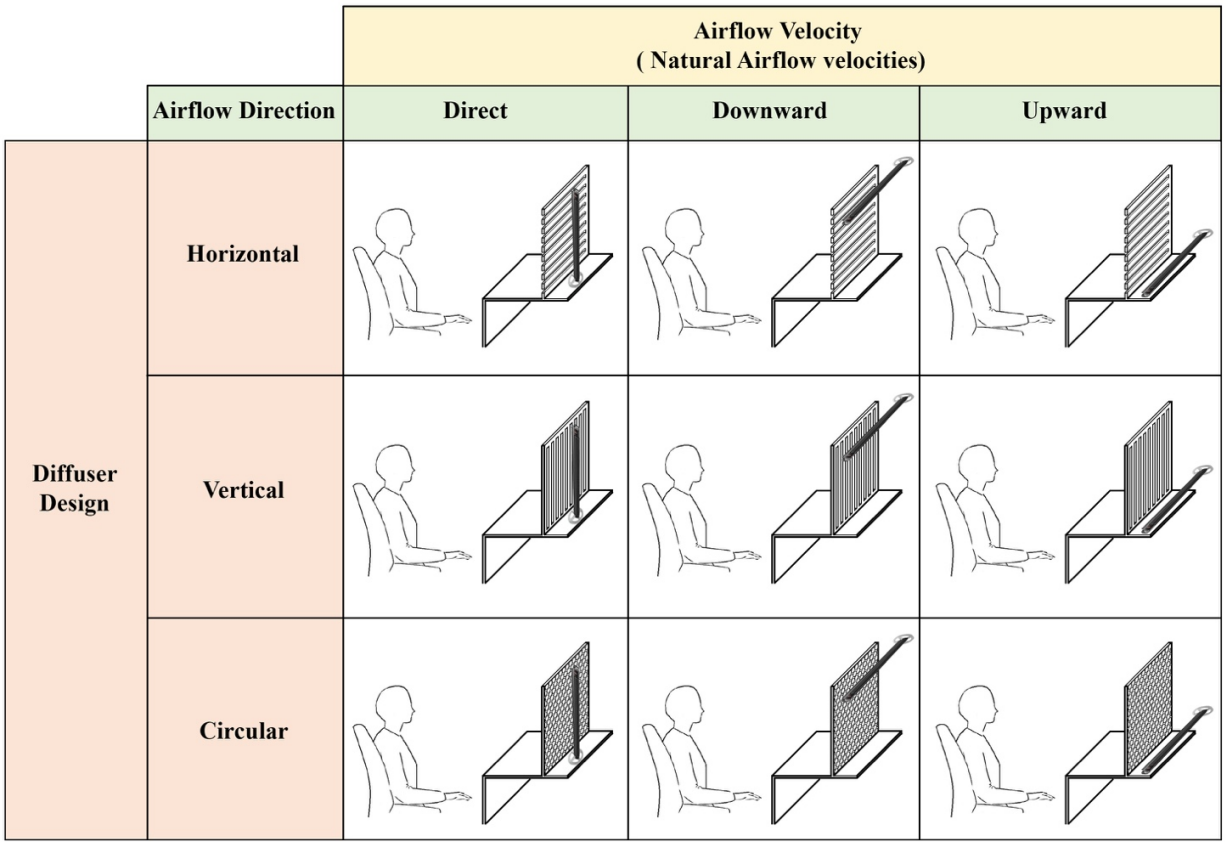

Figure 34: Illustration of Variables and Their Relationships for the Experimental Cases.

5.7.3. Diffusers Designs

As introduced in section 5.7.1, to optimize the distribution of airflow from the BLNAS, attention was given to the design of diffusers. Three distinct designs, vertical, horizontal, and circular, were conceived, each with unique features and configuration of openings.

The designs for these diffusers were rooted in considerations for airflow efficiency and energy conservation. The vertical, horizontal, and circular designs represent configurations known for their ability to minimize the obstruction of the airflow and fan energy required to propel air. The developed designs go beyond mere functionality; they aim to strike a balance between efficiency, aesthetics, and impact on occupant well-being. Efforts were directed towards creating diffusers that are not only efficient in air distribution but also visually appealing. It was imperative to ensure that the design elements did not disrupt the workflow and experience of the occupant nor create visual disturbances. For that, the developed designs have features including:

1. Opening Size and Distribution

A central focus in the diffuser design was the strategic manipulation of opening size and distribution. The size of openings gradually increases from the edges towards the middle of the diffuser, optimizing the airflow pattern by concentrating the flow near the middle. Simultaneously, the distance between openings was increased, contributing to a more controlled and variable pattern of distribution of airflow.

2. Efficiency Considerations

The efficiency by which each design produced a desirable airflow pattern while not restricting the flow was an important consideration. The goal was to create diffusers that not only created airflow patterns that were natural in their variation but also do so in a manner that did not require excessive fan energy. This was achieved by iteratively refining the geometric elements to facilitate a smoother and more efficient flow of air.

Based on the prototype location and direction, these diffusers were rotated to be used vertically or horizontally. Figure 35 represents the vertical, horizontal, and circular diffuser designs

that were used with the horizontal mechanical device orientation and Figure 36 represents the vertical diffuser designs that were used with a vertical mechanical device orientation.

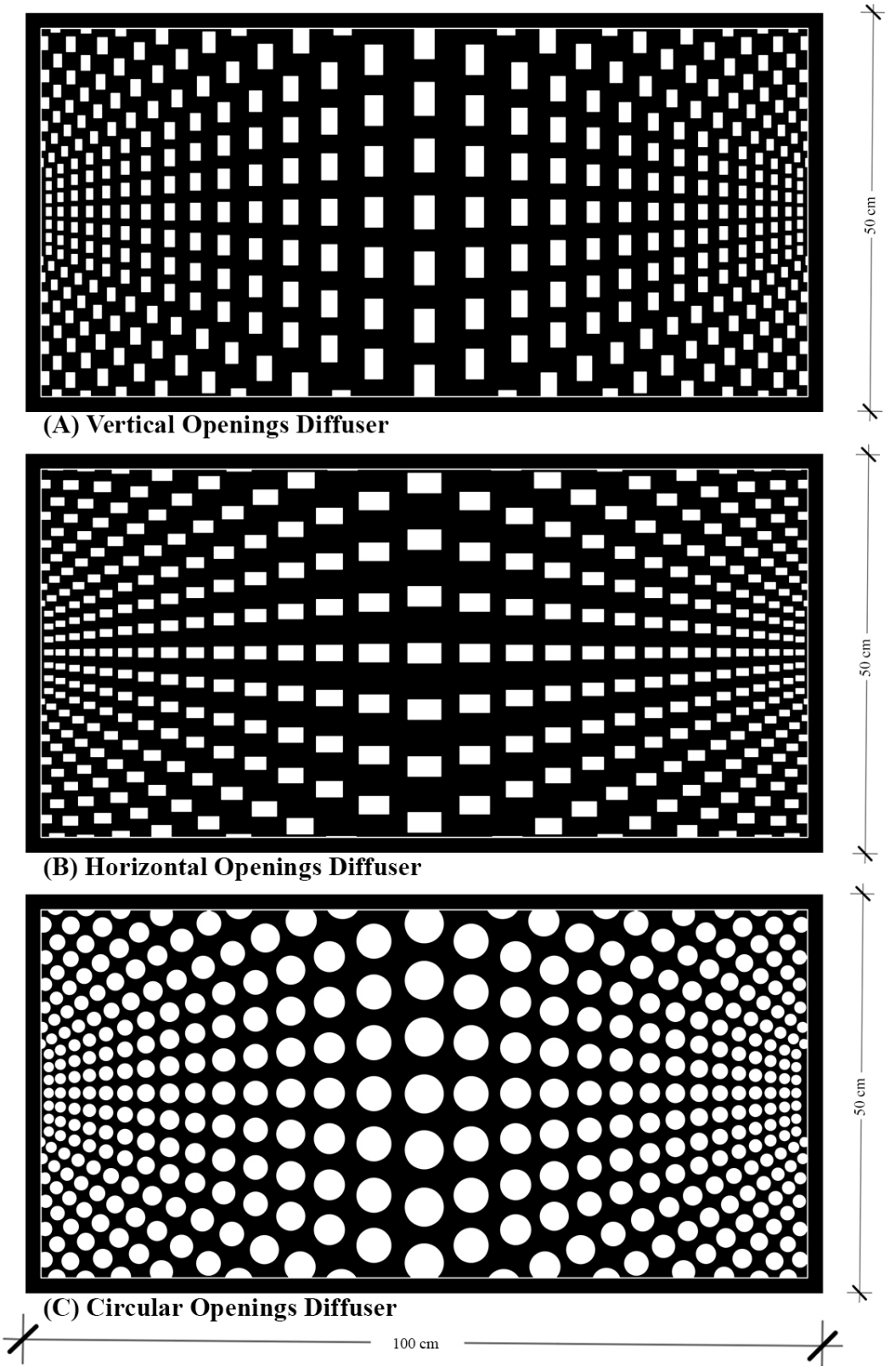

Figure 35: Visual Representation of the Horizontal Diffuser Designs with Vertical, Horizontal, and Circular Openings.

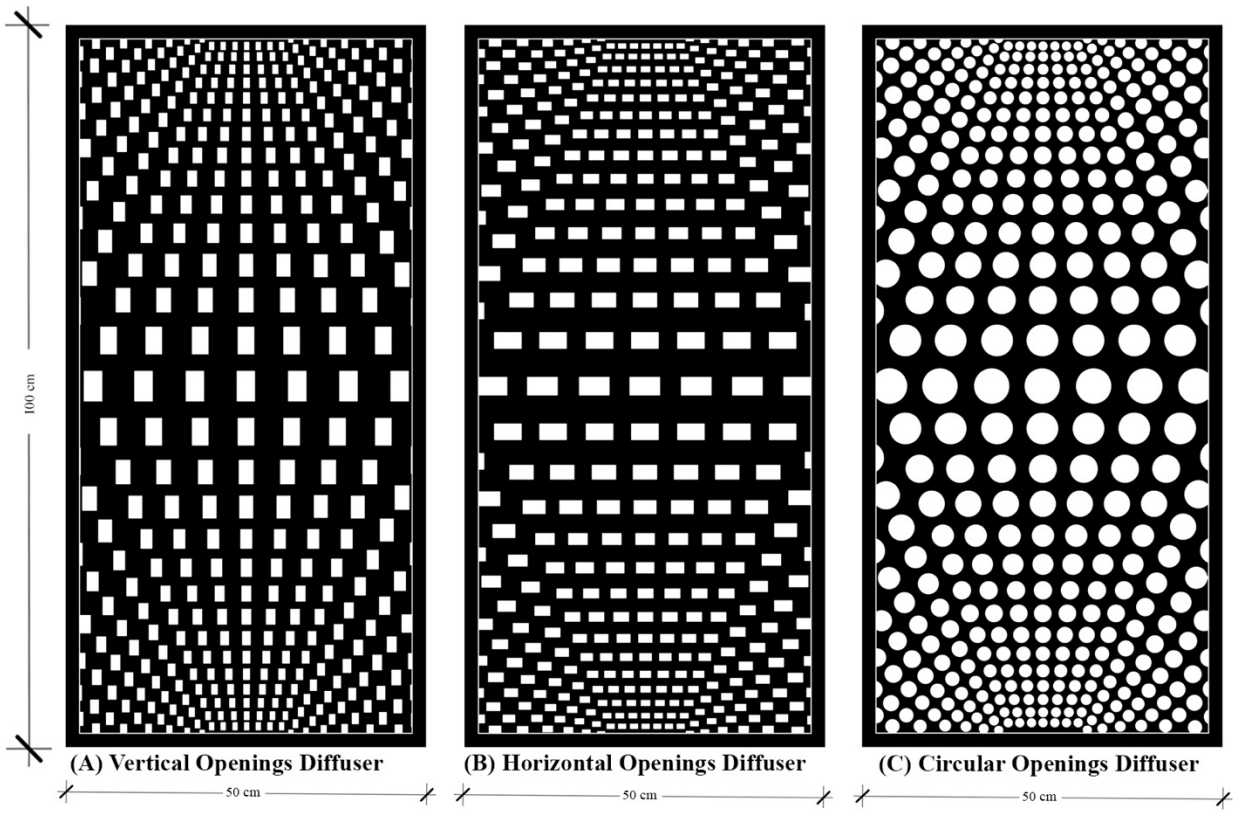

Figure 36: Visual Representation of the Vertical Diffuser Designs with Vertical, Horizontal, and Circular Openings.

5.8. Summary

In summary, the focus of this chapter was on determining the experiment specifications and assumptions. This started by selecting the mechanical device and using criteria to evaluate the advantages of the suggested options and their ability to achieve the research goals and objectives. This step ended up by choosing the Vornado NGT42DC because of its overall advantage score mainly resulting from the large variability in airflow velocity, the turbulence intensity, and device height.

The other step was determining the research workstation. For the purpose, cooperation was established with Steelcase company, and they provided the Flex Collection 120° Straight Height-Adjustable Desk (Model: FLXSWS3A1). Additionally, the research work environment was determined to be GFURR office, which is located at Washington St SW, Blacksburg, VA 24060.

For the purpose of collecting the experimental data, the Campbell Scientific CR1000X datalogger was chosen for its versatility and accuracy, while the LoggerNet software was chosen as a supporting software to collect and store the data. Besides this, the TSI Air Velocity Transducer Model 8465 was employed as a sensor to measure the airflow velocities at the location of the seated occupant. This sensor was chosen because of its high sensitivity and accuracy.

The experimental setup was documented in this chapter. This included assembling the workstation, configuring the datalogger with LoggerNet, and powering the datalogger and the sensor by using a Campbell Scientific CH100 power source supply. Also, it included connecting the datalogger with the TSI air velocity transducer, the sensor's programming and LoggerNet integration, setting up the sensor for experimentation, and setting up the sensor and the mannequin where the mannequin was positioned 70 cm away from the mechanical device and the sensor was positioned between the forehead, cheeks, and nose where the most important thermosensors for humans are found.

This chapter ended with the conclusion of the experimental test setup. In this section, the research variables including airflow velocity and TI at the occupant's location were classified as indigenous dependent variables. The diffuser design (vertical, horizontal, and circular), airflow velocity, and airflow direction (direct, upward, and downward) were classified as indigenous independent variables. The mechanical device location, study location, natural airflow velocities, and Natural airflow TI were classified as exogenous variables. The chapter shed light on the integration between the variables and its resulting experiment scenarios, and the design and specifications of the diffusers. This chapter described and documented every step of the experiment to emphasize the experiment's reliability and provide a source for future research.

6.Chapter Six: Data Collection, Results and Analysis

6.1. Overview of Data Collection Process

The data collection process for the BLNAS experiment was designed to capture the interactions between the mechanical device, diffusers, and the environment. This chapter describes the methodology employed, the challenges encountered, and the iterative nature of adjusting variables to achieve the desired results.

6.1.1. Experimental Setup and Iterative Development of the Prototype

The initial setup involved employed diffusers designed to enhance the airflow toward a more natural distribution. However, the iterative nature of the BLNAS development process revealed that, unfortunately, these diffusers had a significant negative impact on the airflow velocity at the occupant location. The results indicated that the diffusers were interfering with the mechanical device's performance by reducing the airflow at the occupant location to below the target values. As a consequence, the diffusers were excluded from the experiment.

In this initial setup, different distances between the mechanical device and the diffuser were tested including; 5, 10, and 15 cm. For all cases the results indicated that the diffusers significantly reduced the airflow velocity and caused the blades on the mechanical device to stick. Figure 37 presents a schematic representation of the tested distances between the mechanical device and the diffuser for a vertical mechanical device scenario. Tests were performed for these distances for all other scenarios. Figure 38 presents images of the cases tested with different diffusers and with different settings for the mechanical device.

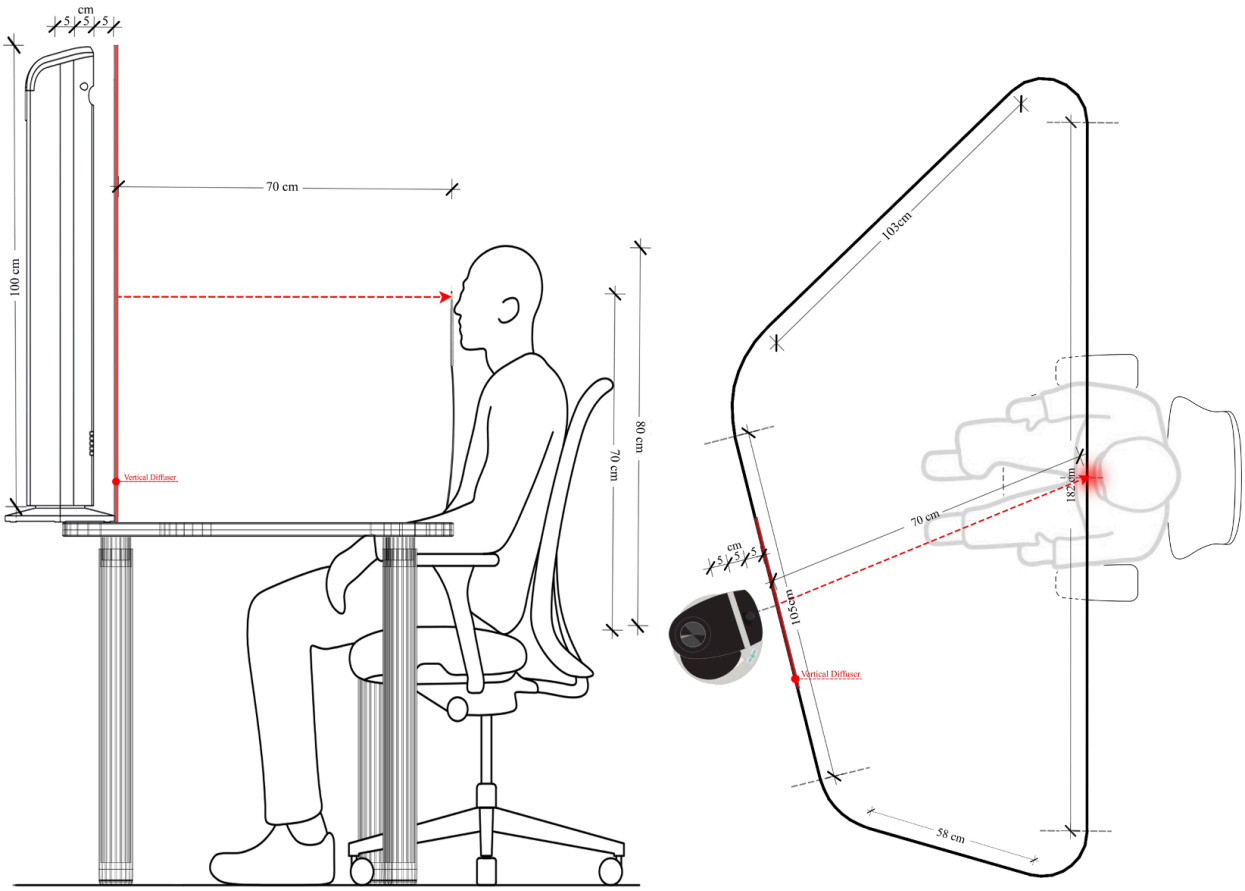

Figure 37: Schematic Representation of the Tested Distances between the Mechanical Device and the Diffuser for a Vertical Mechanical Device Scenario.

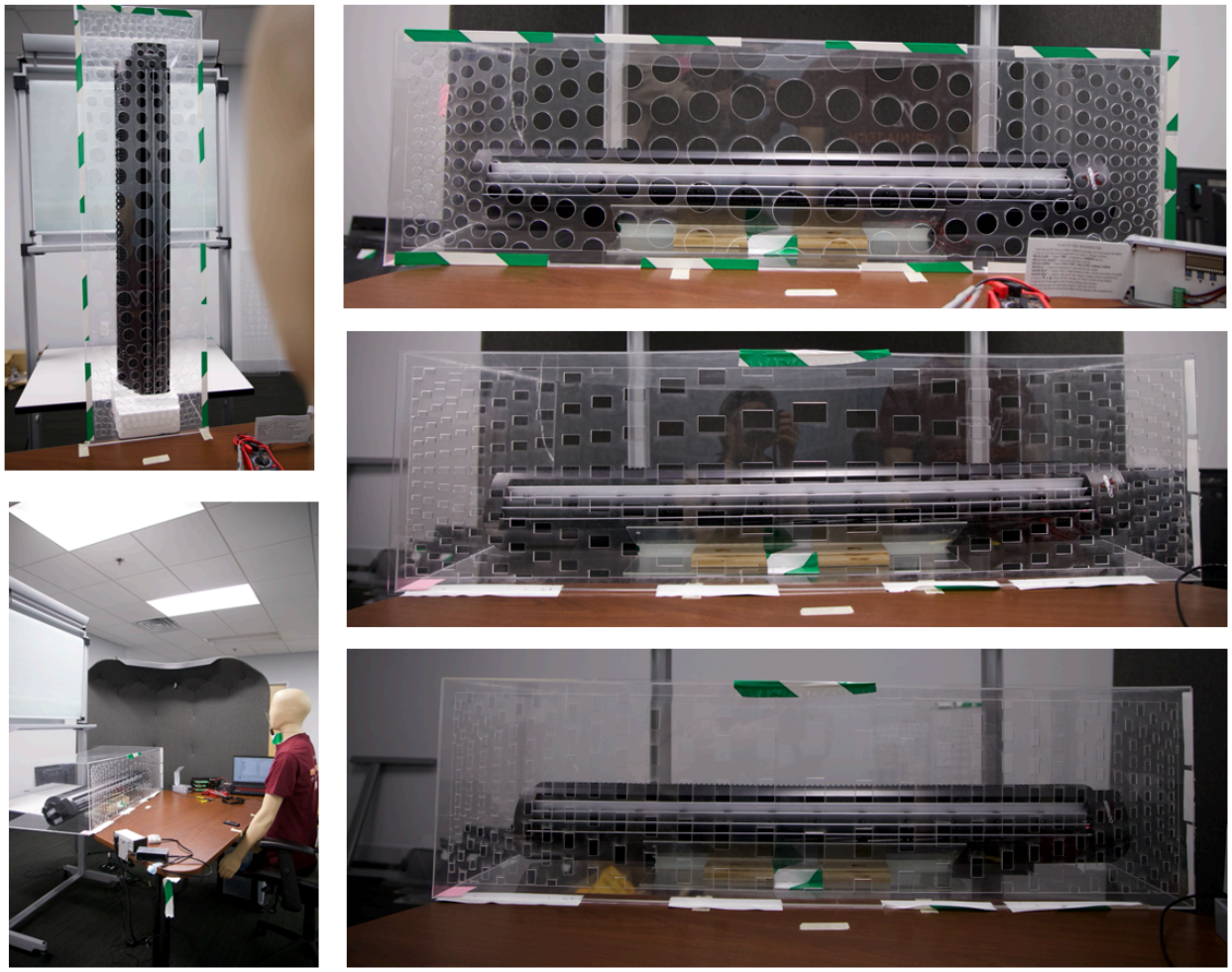

Figure 38: Images of Selected Test Cases While Using Different Settings for the Mechanical Device and Different Diffusers.

6.2. Experimental Variables and Test Cases

6.2.1. Revised Variables and Test Cases

The subsequent phase focused on refining the settings for the variables for optimal airflow. The airflow direction and blade angles emerged as most significant. Four distinct cases were tested: Vertically Directed Airflow, Horizontally Directed Airflow (Upward), Horizontally Directed Airflow (Downward), and Horizontal Direct Airflow. Two blade angles, 0 and 45 degrees, were also explored, resulting in a total of eight cases. Table 14 presents the test cases and variable settings used for developing the BLNAS.

Table 14: Revised Variables and Cases.

		Airflow Velocity			
		Mechanical Device Velocities			
	Mechanical Device Orientation	*Vertical*	*Horizontal*		
	Airflow Direction	*Direct*	*Upward*	*Direct*	*Downward*
Blades' Angle	0^{o}	Case #1	Case #2	Case #3	Case #4
	45^{o}	Case #5	Case #6	Case #7	Case #8

6.3. Data Recording and Results

In the experiment, the air velocity transducer and datalogger were configured to capture dynamic changes in airflow velocities at the occupant location. The measurements were recorded at 10-second intervals, with the sensor programmed to register the maximum airflow velocity during each interval. The objective was to measure the airflow speeds produced by the mechanical device and use it later on to evaluate the performance of the device for each scenario.

To achieve this, a manual control process was implemented. The speed settings of the mechanical device were systematically adjusted from 1 to 99 using a remote control. This adjustment occurred at precise 10-second intervals. Specifically, at every moment when the LoggerNet saved a measurement and updated the timestamp, the remote control was used to change the speed by one setting.

Executing this process was both challenging and demanding, requiring repeated iterations to ensure accuracy. The coordination between the LoggerNet recording intervals and the manual adjustments to the speed of the mechanical device was essential to avoid missing any data points. This methodical approach was undertaken to guarantee the reliability of the recorded measurements and their correspondence to the mechanical device speed settings. The 99 recorded

speeds were measured and documented for each of. The eight test scenarios. The following sections outline the setup, data collection process, and analysis for each scenario.

6.3.1. 0 Degree Blade Angle

This section outlines the experimental configuration for the 0-degree blade angle in conjunction with a vertical and horizontally oriented mechanical device. The aim of this setup was to investigate the impact of these settings on the airflow velocity at the occupant location.

6.3.1.1. Vertically Oriented Mechanical Device

6.3.1.1.1. Direct Forward Airflow

The initial experimental configuration involved a mechanical device oriented in the vertical position with blade angles set at 0 degrees. The mechanical device was strategically positioned in front of the seated occupant, in front of the mannequin, at the midpoint of the side of the workstation. Calibration procedures were implemented to ensure a consistent and controlled airflow throughout the experimental trials, with the specific aim of directing the airflow towards the occupant and the air velocity transducer.

The mechanical device with 0-degree blades was oriented vertically to assess the impact of blade angle and device position and orientation on the airflow velocities at the occupant location. Figure 39 presents a schematic representation of the vertically oriented mechanical device with direct forward airflow and 0-degree blade angle. Figure 40 presents this scenario settings where Table 15 and Figure 41 present the recorded data for this case.

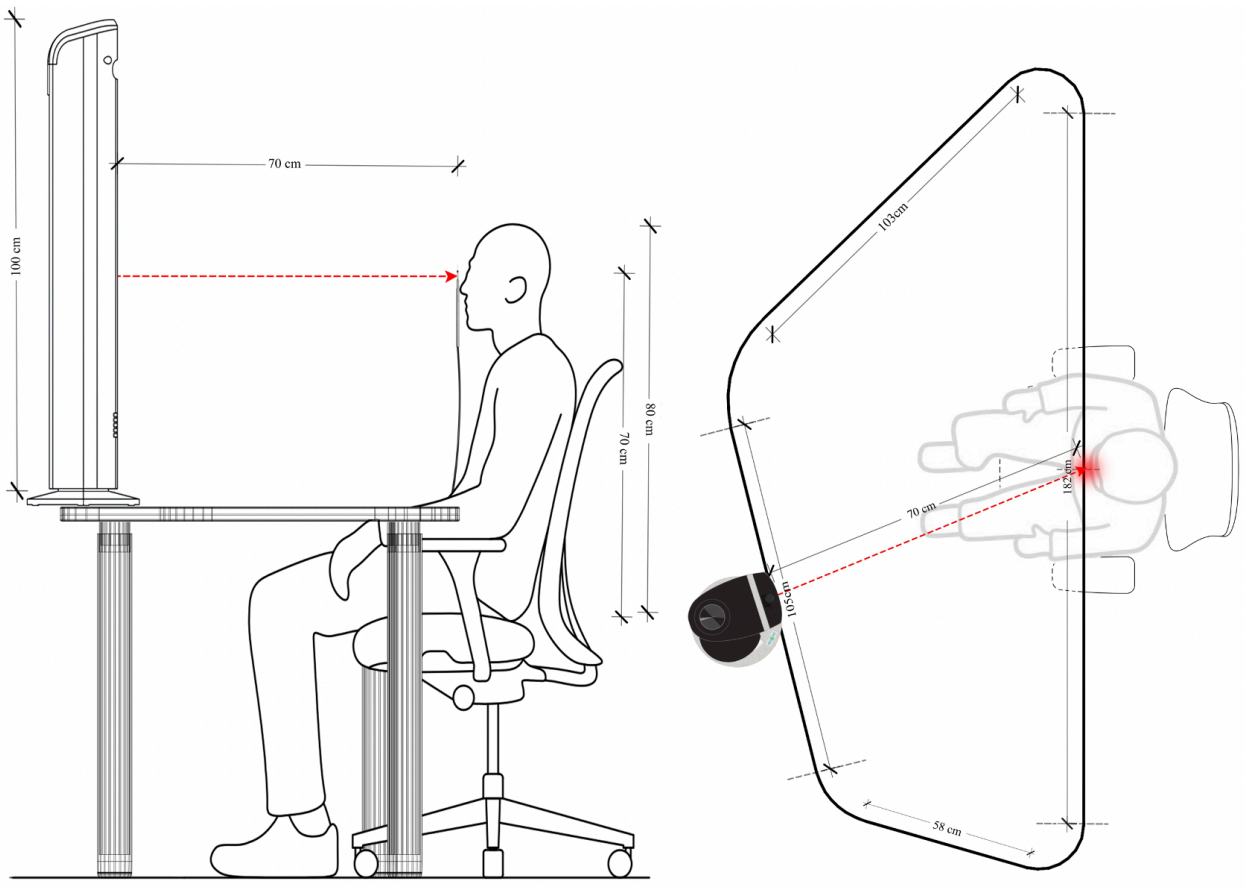

Figure 39: Schematic Representation of the Vertical Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle.

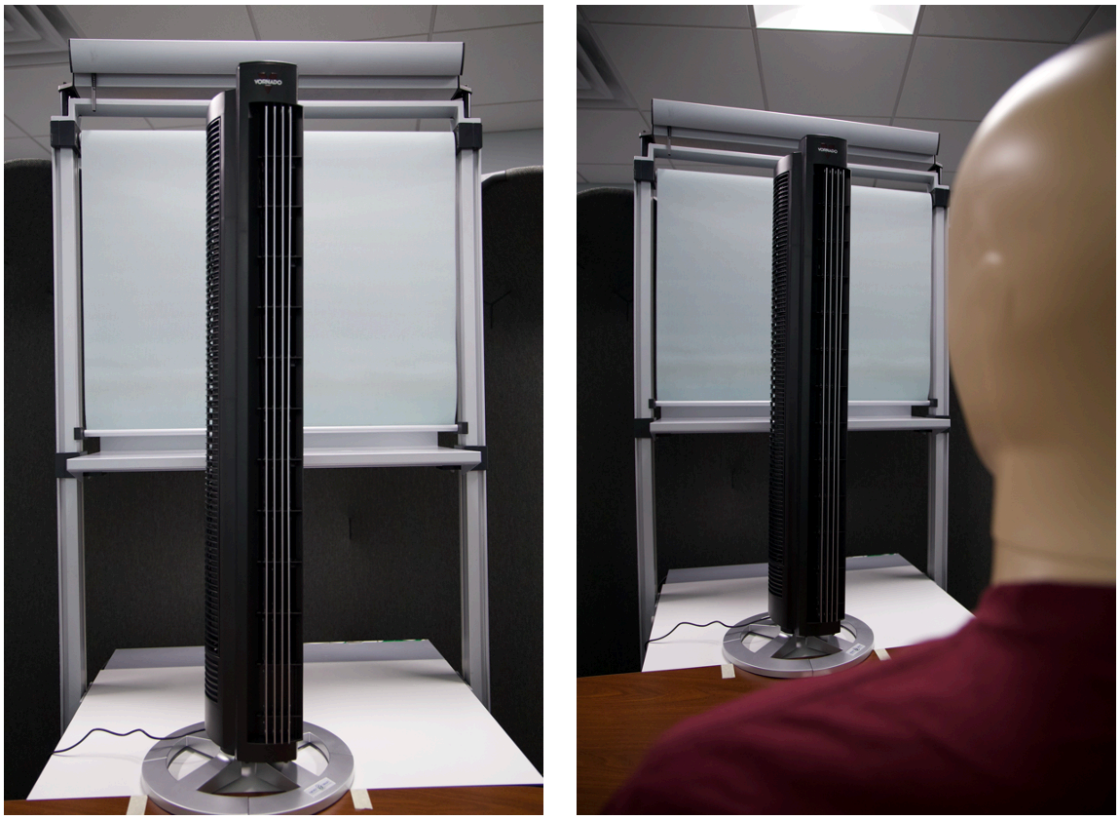

Figure 40: Vertical Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle.

Table 15: Recorded Data for the Vertically Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle.

Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)
1	2.04008928	26	4.59467476	51	6.47370436	76	8.42878992
2	2.1139083	27	4.5409882	52	6.5542342	77	8.52945222
3	2.24365082	28	4.6192811	53	6.74661104	78	8.59879736
4	2.26825716	29	4.65059826	54	6.63029016	79	8.6569578
5	2.28838962	30	4.81165794	55	6.97701586	80	9.06855476
6	2.40694744	31	5.06219522	56	7.0351763	81	9.1267152
7	2.52550526	32	4.9436374	57	7.11123226	82	9.19829728
8	2.6395892	33	5.12482954	58	7.19847292	83	9.3168551
9	2.75814702	34	5.18298998	59	7.15597106	84	9.48015172
10	2.87223096	35	5.2344396	60	7.26110724	85	9.54725992

11	3.01539512	36	5.28588922	61	7.37295424	86	9.41975434
12	3.11829436	37	5.35299742	62	7.48480124	87	9.59870954
13	3.20777196	38	5.38655152	63	7.53625086	88	9.64344834
14	3.29277568	39	5.4693183	64	7.59888518	89	9.77990168
15	3.47173088	40	5.54313732	65	7.67941502	90	9.95661994
16	3.39567492	41	5.59235	66	7.77784038	91	10.0170173
17	3.58805176	42	5.76683132	67	7.82481612	92	10.0751778
18	3.70660958	43	5.81157012	68	7.89192432	93	10.1959725
19	3.77371778	44	6.06881822	69	7.95679558	94	10.2630807
20	3.82740434	45	5.94354958	70	8.07087952	95	10.3167673
21	3.95490992	46	6.11355702	71	8.01271908	96	10.4286143
22	4.05780916	47	6.18066522	72	8.05969482	97	10.5158549
23	4.1830778	48	6.28356446	73	8.12903996	98	10.6053325
24	4.12491736	49	6.31040774	74	8.21851756	99	10.663493
25	4.2278166	50	6.37751594	75	8.30128434		

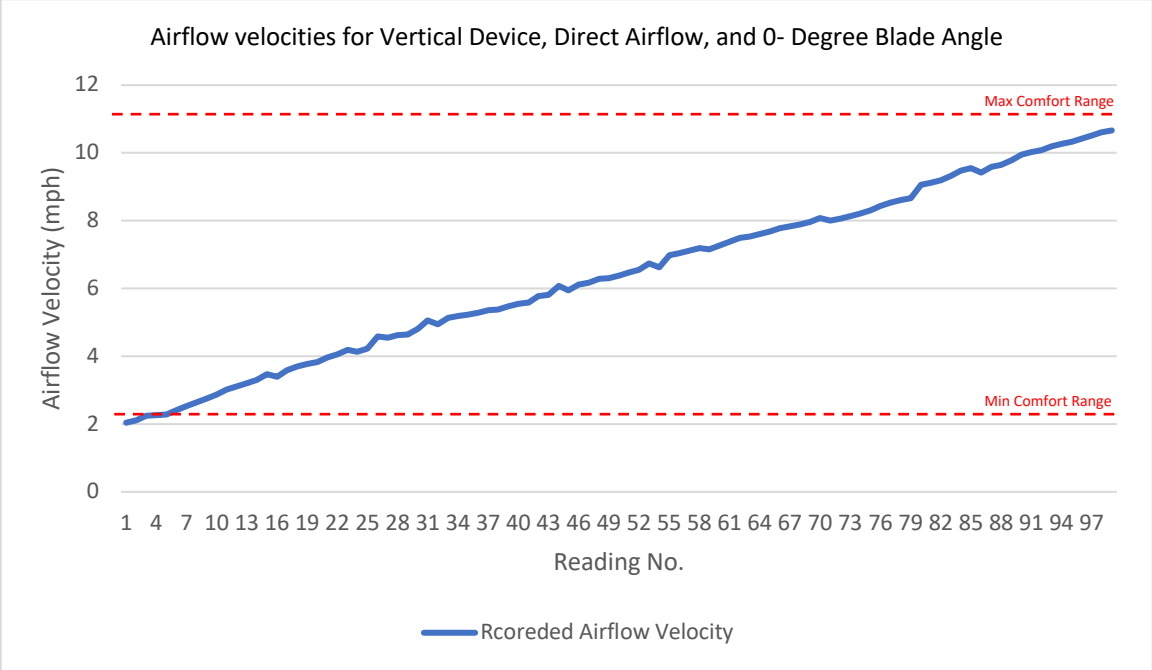

Figure 41: Recorded Data for the Vertically Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle.

6.3.1.2. Horizontally Oriented Mechanical Device

The subsequent experimental configurations introduced a horizontally oriented mechanical device with 0-degree blade angle. The mechanical device was strategically placed at the midpoint on the side of the workstation, perpendicular to the location of the seated occupant. This experimental configuration included 3 cases; direct upward airflow, direct forward airflow, and direct downward airflow. Below is a description for each case.

6.3.1.2.1. Direct Upward Airflow

Besides the settings previously introduced, calibration procedures were applied to achieve consistent and controlled airflow during the experimental trials, while ensuring precise directional airflow towards the occupant and the air velocity transducer. For this scenario, the device was tilted up at a 35-degree angle to enhance the direction of the airflow toward the air velocity transducer. Several angles were tested including; 30, 35, 40, and 45 degrees.

Angles lower than 30 degrees were excluded because the majority of the airflow was below the height of the sensor and Angles above 45 degrees were excluded because the airflow was above the sensor. The selected Angles mostly directed the airflow to the sensor but had a different impact. The resulting airflow velocities of these angles were observed, and the 35-degree angle was determined as the best because it resulted in the highest airflow velocities. This happened because the center of the mechanical device was directly toward the center of the sensor. Figure 42 presents the process of choosing the best upward tilting angle.

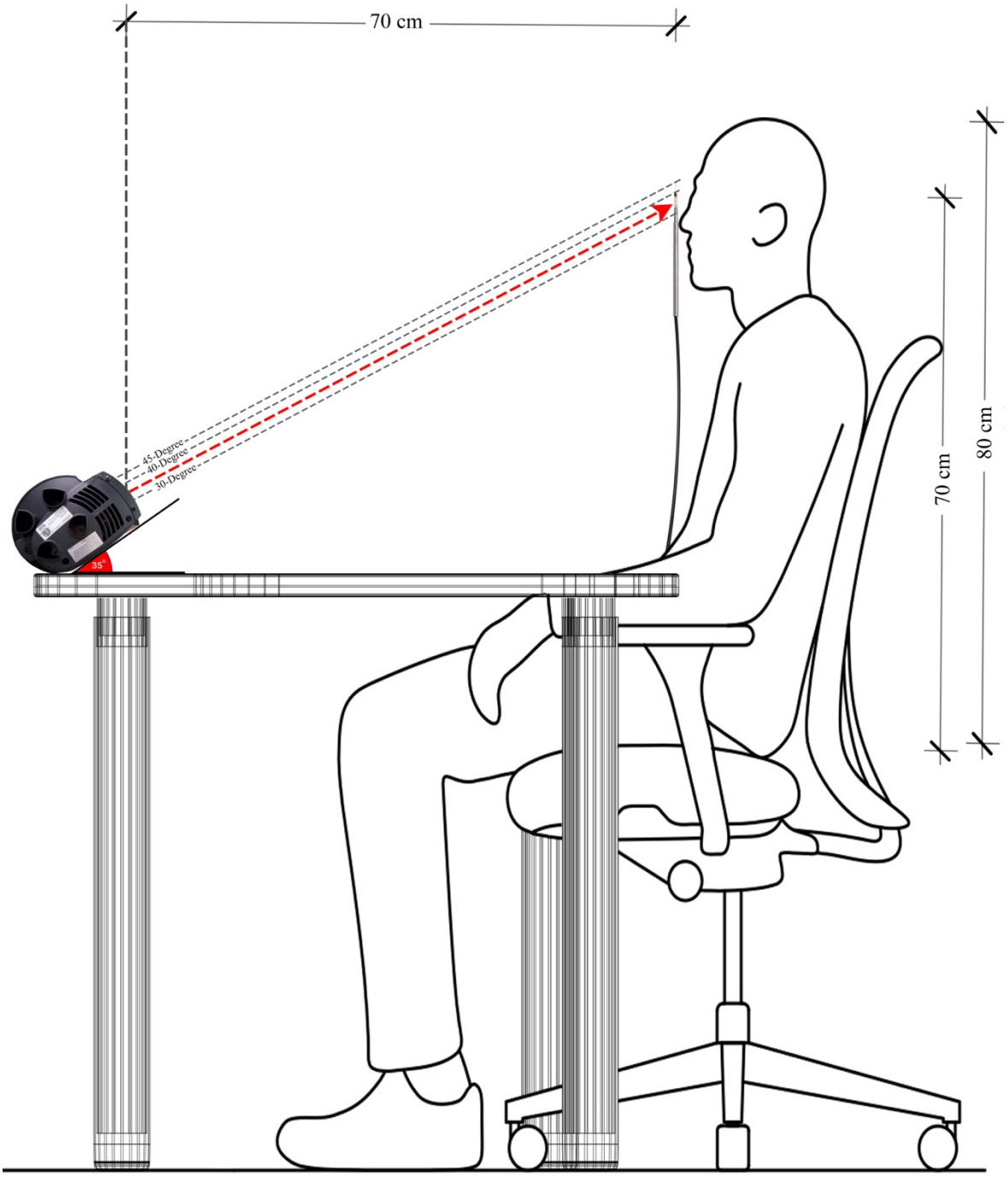

Figure 42: The Process of Testing the Device's Best Upward Tilting Angle.

Figure 43 presents a schematic representation of the horizontally oriented mechanical device with direct upward airflow and 0-degree blade angle. For this scenario, Figure 44 presents the experimental setup while Table 16 and Figure 45 present the recorded data.

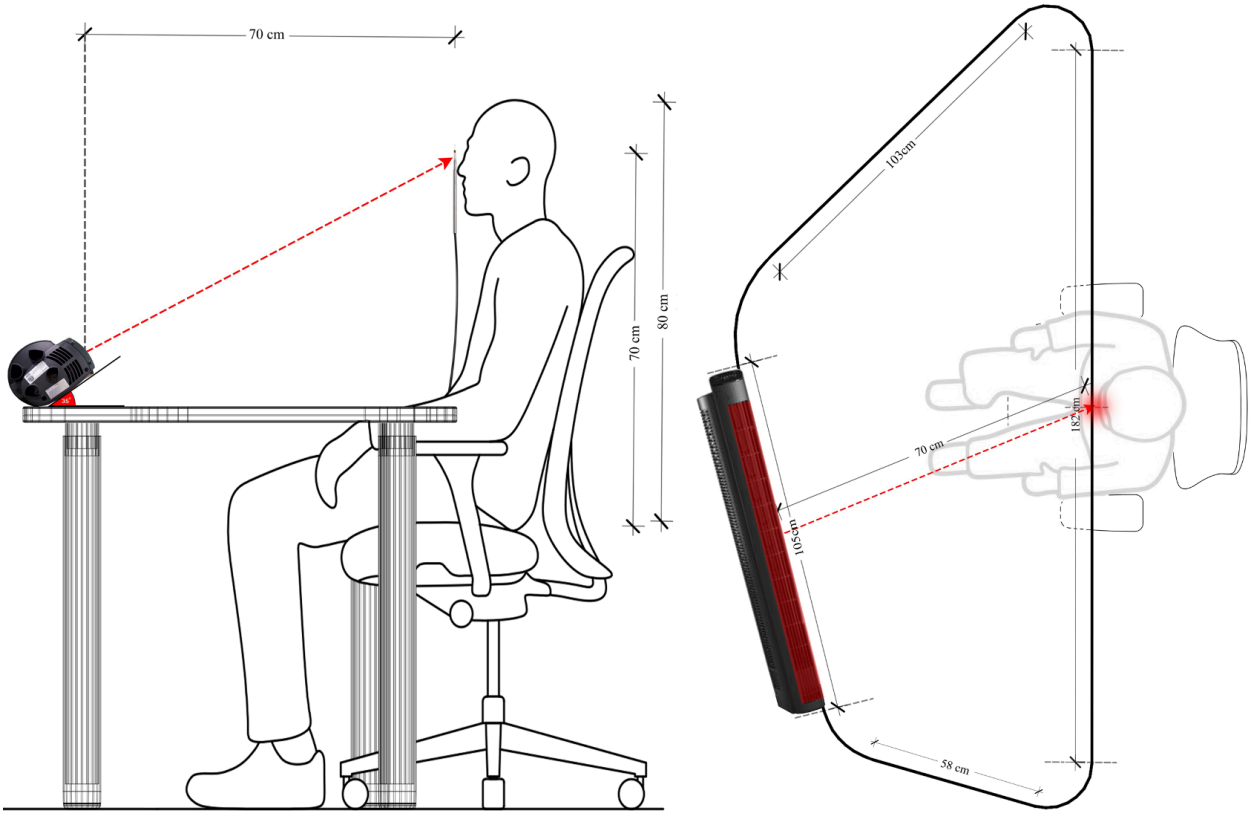

Figure 43: Schematic Representation of the Horizontal Mechanical Device with Direct Upward Airflow and 0-Degree Blade Angle.

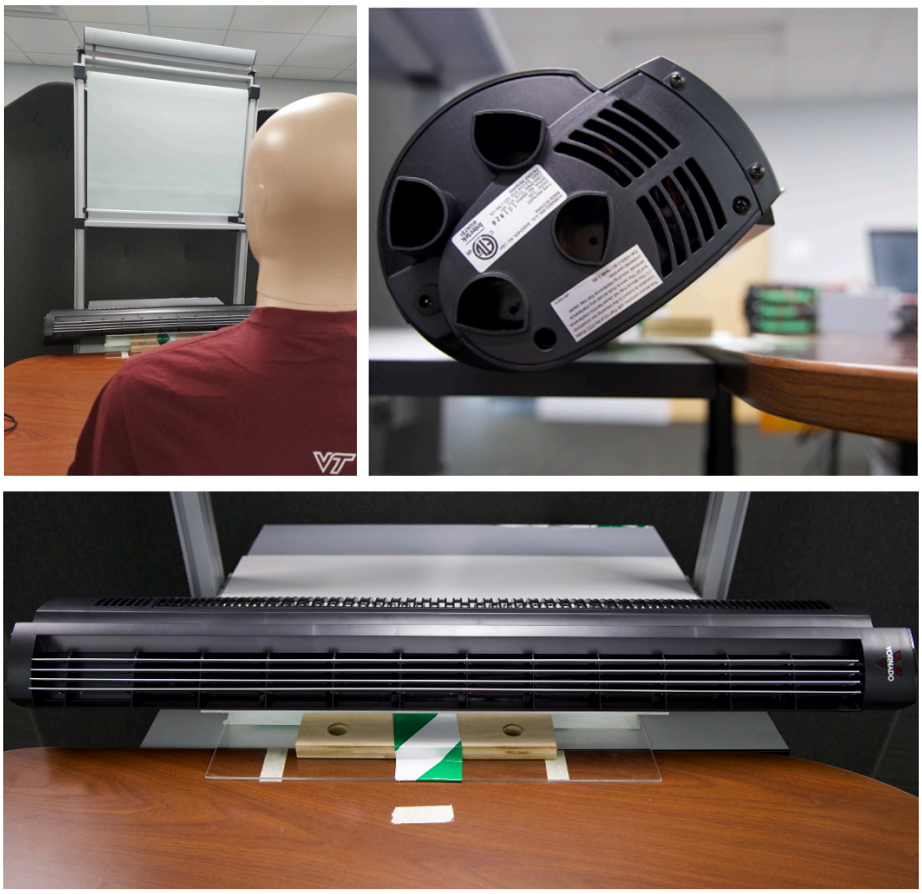

Figure 44: Horizontal Mechanical Device with Upward Directed Airflow and 0-Degree Blade Angle.

Table 16: Recorded Data for the Horizontally Oriented Mechanical Device with Upward Directed Airflow and 0-Degree Blades Angle.

Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)
1	0.13869028	26	1.0849159	51	4.18531474	76	6.22764096
2	0.1454011	27	0.96859502	52	4.31058338	77	6.24777342
3	0.15211192	28	1.14755022	53	4.47835388	78	6.37304206
4	0.15882274	29	1.2079476	54	4.4179565	79	6.45804578
5	0.16553356	30	1.32203154	55	4.57901618	80	6.52291704
6	0.17448132	31	1.52335614	56	4.6863893	81	6.56318196
7	0.18566602	32	1.4092722	57	4.81613182	82	6.61686852
8	0.19237684	33	1.63967702	58	4.97942844	83	6.69292448

9	0.19908766	34	1.75152402	59	4.8877139	84	6.94793564
10	0.20579848	35	1.9349531	60	5.0666691	85	7.01504384
11	0.2125093	36	1.82981692	61	5.08009074	86	6.8338517
12	0.21698318	37	1.94166392	62	5.1897008	87	7.0799151
13	0.22145706	38	2.06022174	63	5.28588922	88	7.15373412
14	0.24830034	39	2.17877956	64	5.38655152	89	7.20070986
15	0.40936002	40	2.27944186	65	5.47826606	90	7.28347664
16	0.32211936	41	4.03543976	66	5.4916877	91	7.36848036
17	0.42725554	42	2.66643248	67	5.5364265	92	7.49822288
18	0.35119958	43	2.88341566	68	5.65274738	93	7.5496725
19	0.40936002	44	3.47173088	69	5.7153817	94	7.66823032
20	0.50107456	45	3.52989132	70	5.81157012	95	7.78007732
21	0.58384134	46	3.77819166	71	5.82499176	96	7.83823776
22	0.66437118	47	3.82964128	72	5.90328466	97	8.01271908
23	0.72253162	48	4.00635954	73	5.99947308	98	8.30575822
24	0.76950736	49	4.07794162	74	6.05763352	99	8.42431604
25	0.84108944	50	4.1718931	75	6.1068462		

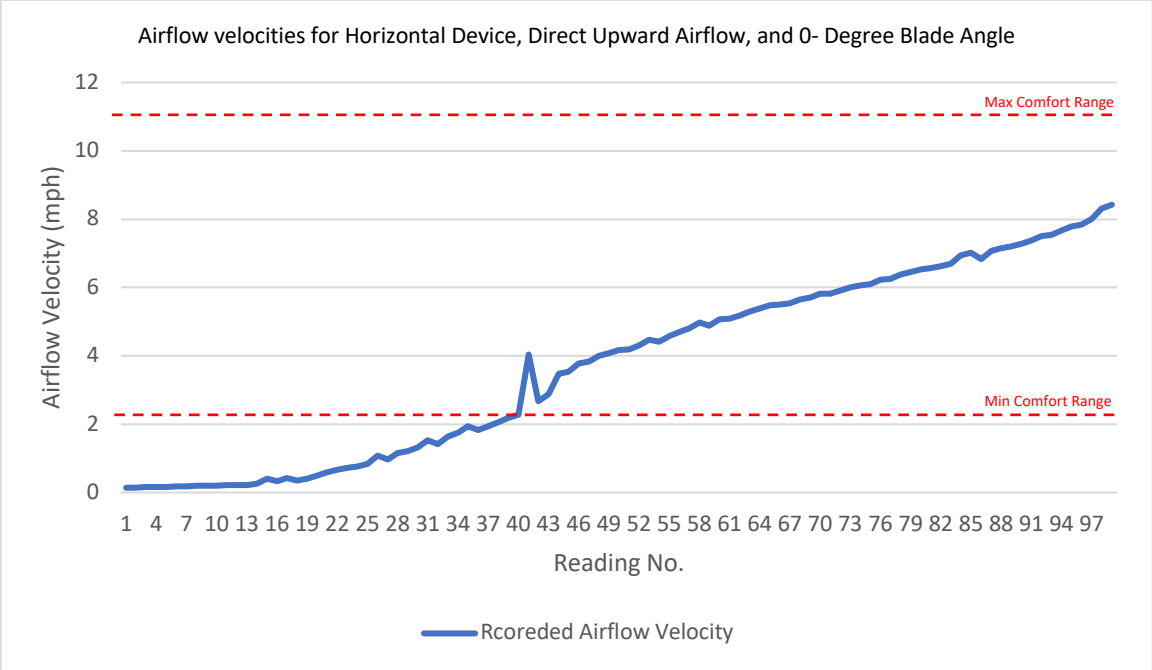

Figure 45: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Upward Airflow and 0-Degree Blade Angle.

6.3.1.2.2. Direct Forward Airflow

For all of the case configurations, stringent calibration procedures were implemented to insure consistent and controlled airflow while ensuring precise directionality targeted at the occupant and air velocity transducer. Specifically tailored for this scenario, the mechanical device remained fixed at the level of the occupant's head, aligning with the location for the air velocity transducer. In this setup, the device was horizontally oriented with 0-degree tilt, positioned perpendicular to the occupant and air velocity transducer. Figure 46 presents a schematic representation of the horizontal mechanical device with direct forward airflow and 0-degree blade angle. The settings for this scenario are presented in Figure 47 and the recorded data are presented in Table 17 and Figure 48.

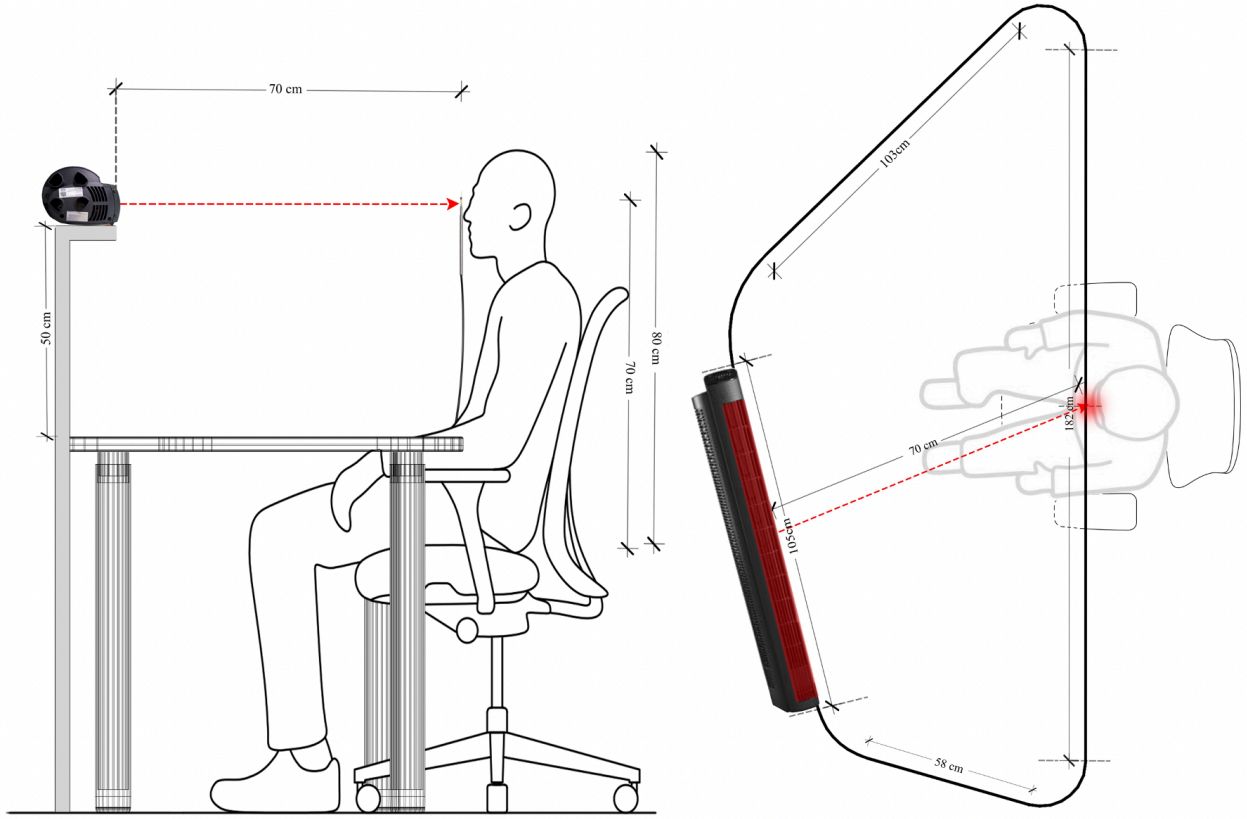

Figure 46: Schematic Representation of the Horizontal Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle.

Figure 47: Horizontally Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blades Angle.

Table 17: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle.

Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)
1	1.99758742	26	4.41571956	51	6.3976484	76	8.59879736
2	2.11167136	27	4.29939868	52	6.45804578	77	8.65919474
3	2.17206874	28	4.44256284	53	6.72424164	78	8.75314622
4	2.23022918	29	4.47611694	54	6.6884506	79	8.82025442
5	2.29733738	30	4.53427738	55	6.73542634	80	8.94999694
6	2.40247356	31	4.76915608	56	6.74661104	81	9.06855476
7	2.46958176	32	4.71099564	57	6.80477148	82	9.10881968
8	2.5277422	33	4.8206057	58	7.02846548	83	9.1826387
9	2.58813958	34	4.88547696	59	6.92109236	84	9.35488308
10	2.76709478	35	4.9436374	60	7.15597106	85	9.43541292
11	2.87670484	36	5.0666691	61	7.20518374	86	9.29001182
12	2.9415761	37	5.17404222	62	7.26334418	87	9.50475806
13	3.06013392	38	5.23667654	63	7.31926768	88	9.56515544
14	3.11829436	39	5.29483698	64	7.43335162	89	9.62331588
15	3.41357044	40	5.41115786	65	7.59888518	90	9.71279348
16	3.23461524	41	5.54313732	66	7.66375644	91	9.83806212

17	3.4113335	42	5.61919328	67	7.605596	92	9.95885688
18	3.52989132	43	5.71761864	68	7.73757546	93	10.1959725
19	3.64844914	44	5.82499176	69	7.83823776	94	10.2407113
20	3.76700696	45	5.8831522	70	7.95455864	95	10.4196665
21	3.82740434	46	6.11355702	71	8.12903996	96	10.5091441
22	3.87885396	47	6.05539658	72	8.24759778	97	10.5538829
23	4.13162818	48	6.22764096	73	8.3214168	98	10.5807262
24	4.02201812	49	6.28356446	74	8.48023954	99	10.6388866
25	4.1830778	50	6.3417249	75	8.53168916		

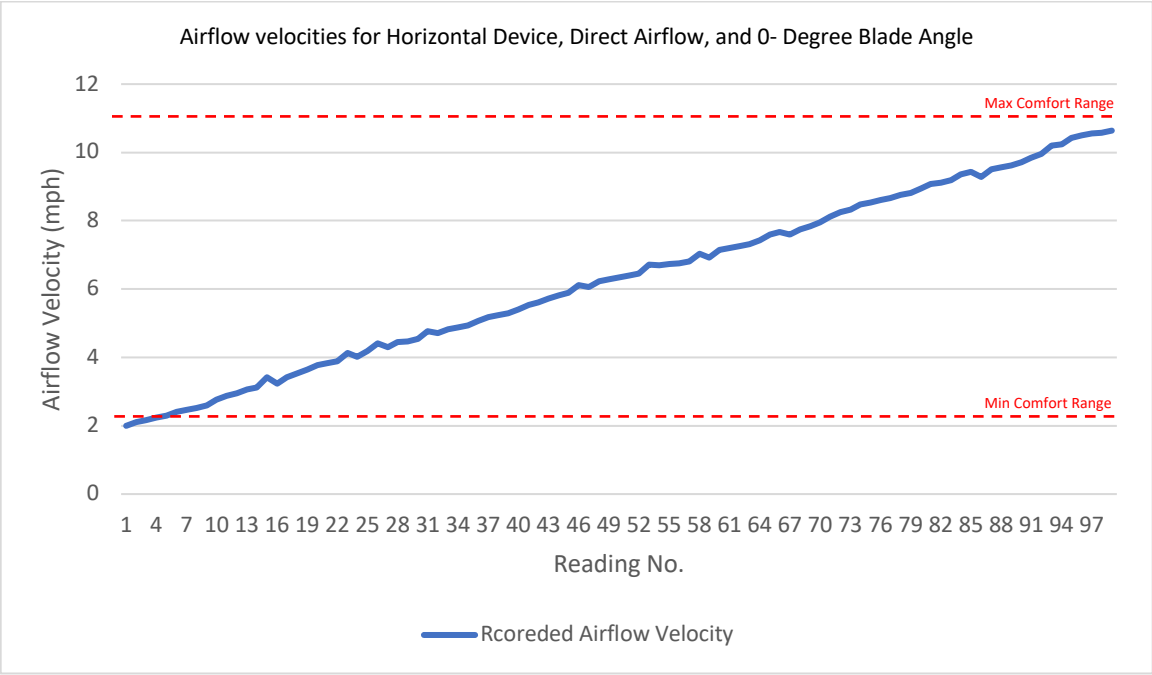

Figure 48: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Forward Airflow and 0-Degree Blade Angle.

6.3.1.2.3. Direct Downward Airflow

For this experimental setup, the mechanical device was positioned above the level of the occupants' head. As described in section 6.3.1.2.1, to channel the airflow towards the air velocity transducer, the device was tilted downward at a 35-degree angle. Figure 49 presents the process of choosing the best downward tilting angle. Figure 50 presents a schematic representation of the horizontally oriented mechanical device with direct downward airflow and 0-degree blade angle.

Figure 51 presents the settings for this scenario and the resulting data are shown in Table 18 and Figure 52.

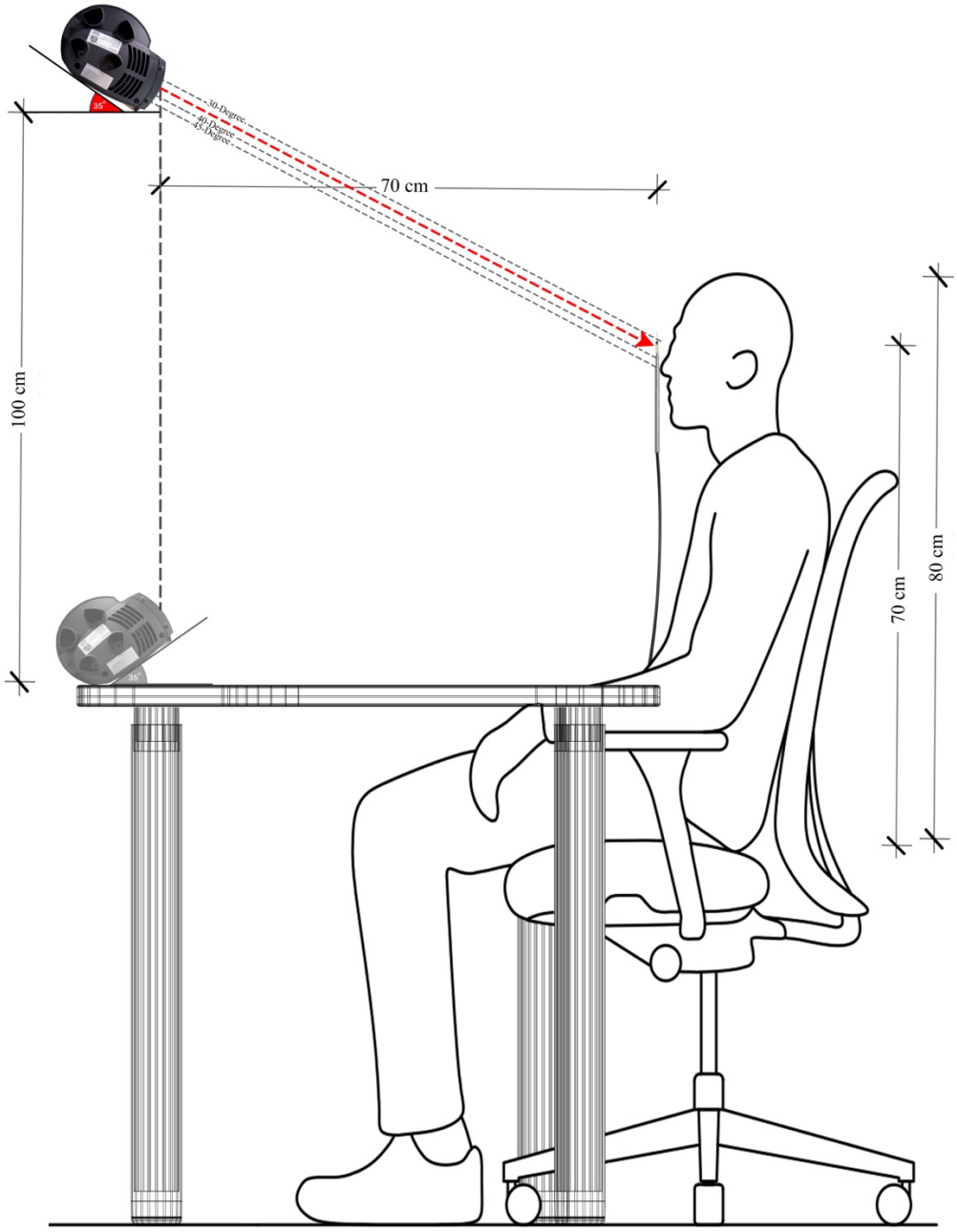

Figure 49: The Process of Testing the Device's Best Downward Tilting Angle.

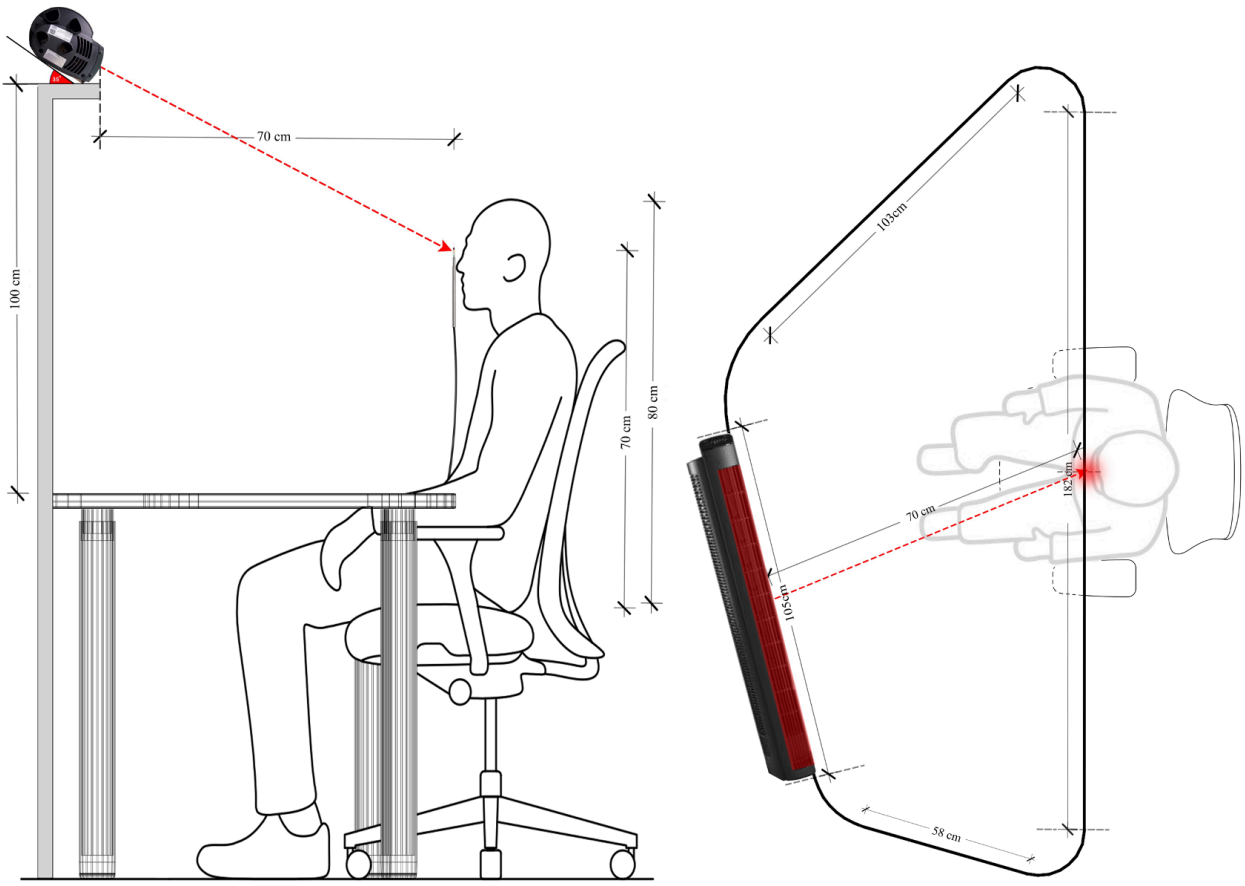

Figure 50: Schematic Representation of the Horizontal Mechanical Device with Direct Downward Airflow and 0-Degree Blade Angle.

Figure 51: Horizontally Oriented Mechanical Device with Direct Downward Airflow and 0-Degree Blade Angle.

Table 18: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Downward Airflow and 0-Degree Blade Angle.

Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)
1	1.39137668	26	2.69774964	51	5.6147194	76	7.57427884
2	1.48085428	27	2.72459292	52	5.72209252	77	7.63243928
3	1.52559308	28	2.75814702	53	5.7489358	78	7.7621818
4	1.60388598	29	2.77604254	54	5.7601205	79	7.84942246
5	1.69112664	30	2.80288582	55	5.79591154	80	7.93442618
6	1.71349604	31	2.83196604	56	5.80709624	81	8.03285154
7	1.78731506	32	2.84986156	57	5.83393952	82	8.1089075
8	1.83876468	33	2.89907424	58	5.87867832	83	8.16035712

9	1.84994938	34	3.03776452	59	5.92565406	84	8.22970226
10	1.89692512	35	3.11158354	60	5.93683876	85	8.31694292
11	1.93271616	36	3.24579994	61	6.09118762	86	8.31917986
12	1.95061168	37	3.27264322	62	6.16500664	87	8.36839254
13	1.99982436	38	3.28159098	63	6.35514654	88	8.43773768
14	2.07364338	39	3.29277568	64	6.78240208	89	8.52050446
15	2.11167136	40	3.37106858	65	6.84056252	90	8.56300632
16	2.13851464	41	3.5231805	66	6.87411662	91	8.69498578
17	2.1698318	42	4.18755168	67	6.9568834	92	8.8023589
18	2.24365082	43	4.7758669	68	7.0910998	93	8.86051934
19	2.25259858	44	4.83402734	69	7.11570614	94	9.08421334
20	2.44721236	45	5.04206276	70	7.12912778	95	9.12000438
21	2.48971422	46	5.1114079	71	7.18505128	96	9.3615939
22	2.52103138	47	5.13154036	72	7.2812397	97	9.63226364
23	2.54787466	48	5.27023064	73	7.36176954	98	9.70608266
24	2.60827204	49	5.43129032	74	7.45572102	99	9.72621512
25	2.67538024	50	5.48945076	75	7.53177698		

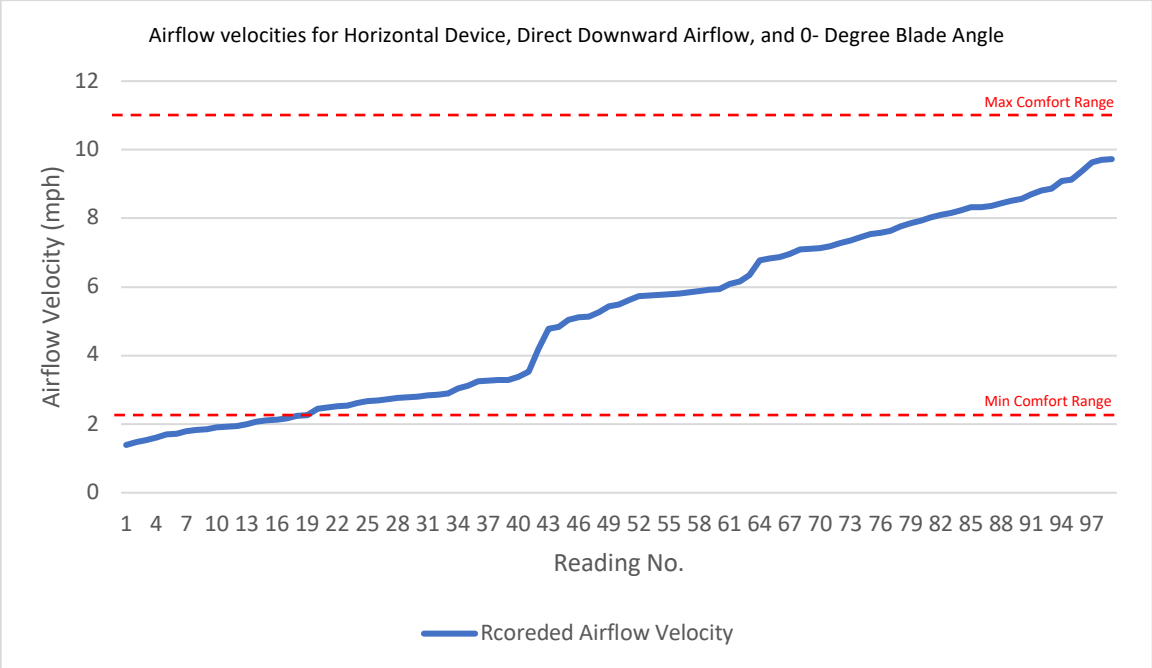

Figure 52: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Downward Airflow and 0-Degree Blade Angle.

6.3.2. 45 Degree Blade Angle

This section outlines the experimental configuration involving the 45-degree blade angle in conjunction with a vertically or horizontally oriented mechanical device. The aim of this setup was to investigate the impact of these settings on the airflow velocity at the occupant location.

6.3.2.1. Vertically Oriented Mechanical Device

6.3.2.1.1. Direct Forward Airflow

This scenario involved a vertically oriented mechanical device with blades set at 45 degrees. The mechanical device was positioned at the midpoint to the side of the workstation, directly in front of the mannequin and the velocity sensor. These procedures were designed to establish and maintain consistent and controlled airflow throughout the experimental trials, while directing the airflow toward the air velocity transducer.

The mechanical device, equipped with blades set at 45 degrees, was vertically oriented to investigate the influence of blade angle and the positioning of the device on airflow velocities at the seated occupant location. Figure 53 presents a schematic representation of the vertical mechanical device with direct forward airflow and 45-degree blade angle. The settings for this scenario are presented in Figure 54 and the recorded data are shown in Table 19 and Figure 55.

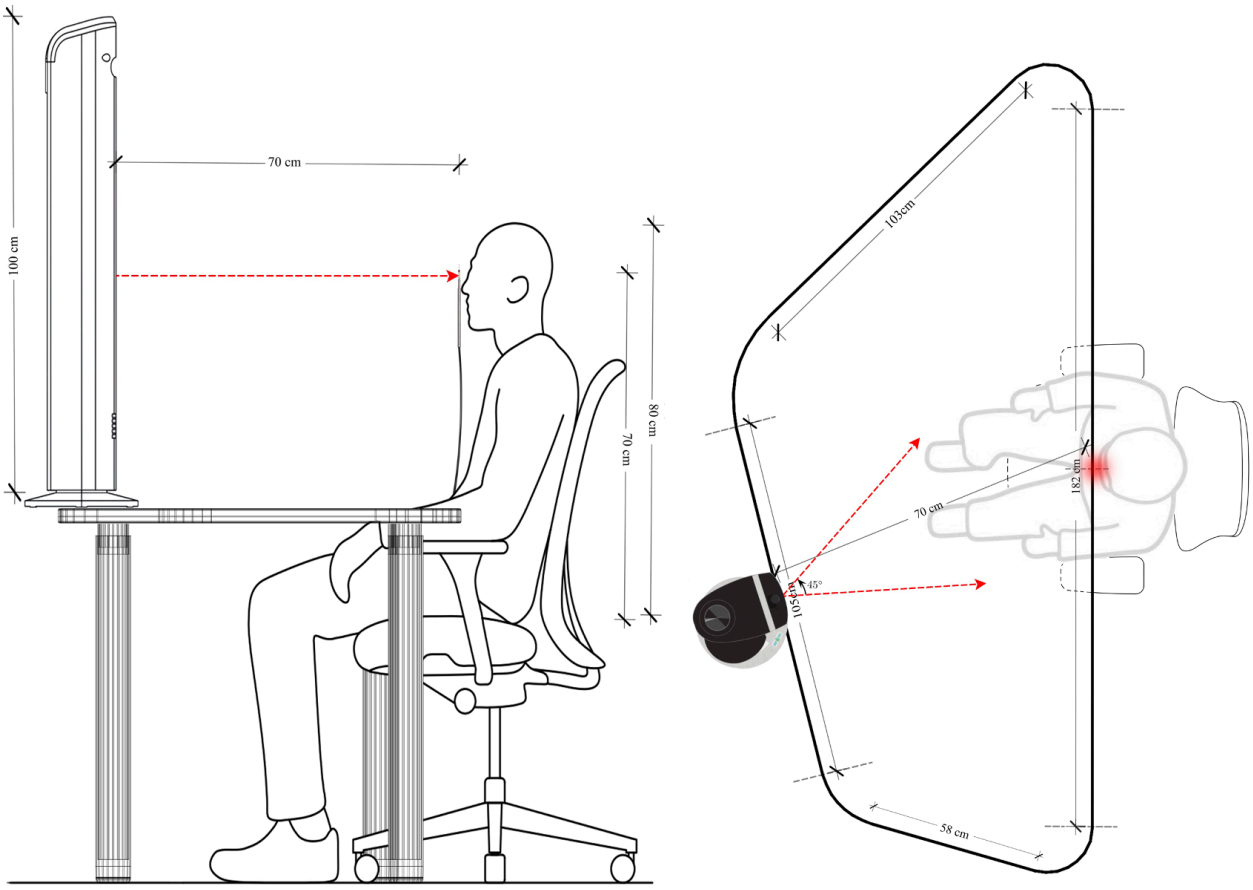

Figure 53: Schematic Representation of the Vertical Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle.

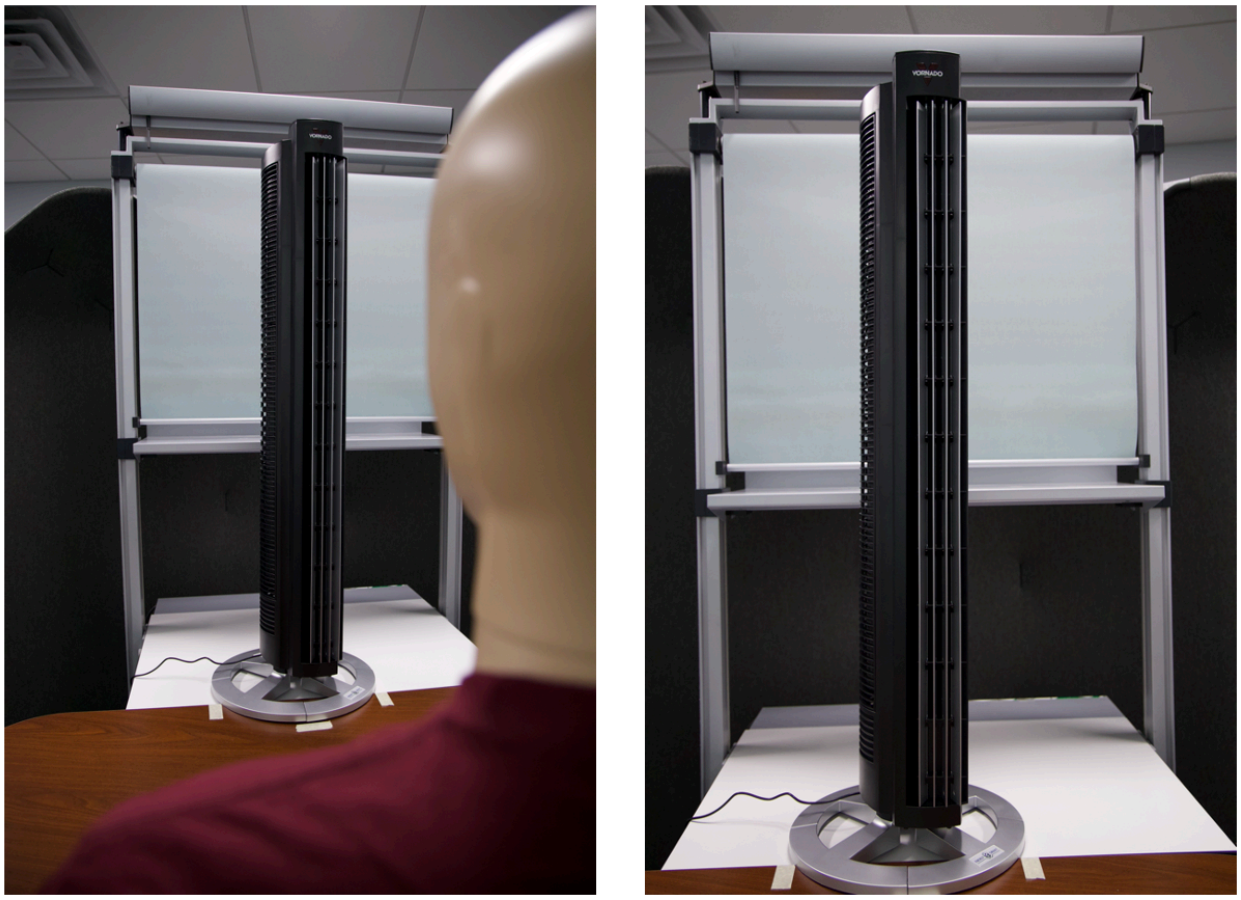

Figure 54: Vertically Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle.

Table 19: Recorded Data for the Vertically Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle.

Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)
1	1.30413602	26	3.0534231	51	4.51414492	76	6.31264468
2	1.36677034	27	3.10263578	52	4.52756656	77	6.44686108
3	1.43611548	28	3.17198092	53	4.54546208	78	6.61463158
4	1.52335614	29	3.20106114	54	4.66178296	79	6.6772659
5	1.59046434	30	3.22343054	55	4.7087587	80	6.74661104
6	1.63967702	31	3.2883018	56	4.77362996	81	6.79358678
7	1.70678522	32	3.37106858	57	4.81836876	82	6.8785905
8	1.77389342	33	3.38672716	58	4.8765292	83	6.90767072

9	1.88797736	34	3.48515252	59	4.89666166	84	6.9121446
10	1.96179638	35	3.54331296	60	5.00850866	85	6.99938526
11	2.00653518	36	3.66187078	61	5.08232768	86	7.03070242
12	2.08706502	37	3.66410772	62	5.16956834	87	7.08662592
13	2.23022918	38	3.78266554	63	5.2344396	88	7.14478636
14	2.348787	39	3.8251674	64	5.35076048	89	7.26110724
15	2.46734482	40	3.89674948	65	5.39773622	90	7.33045238
16	2.48971422	41	3.94372522	66	5.47155524	91	7.36176954
17	2.5501116	42	4.0041226	67	5.56774366	92	7.4266408
18	2.65748472	43	4.13386512	68	5.6259041	93	7.43111468
19	2.70893434	44	4.19649944	69	5.68630148	94	7.54072474
20	2.76709478	45	4.25242294	70	5.71314476	95	7.54743556
21	2.77604254	46	4.34190054	71	5.77577908	96	7.72191688
22	2.8409138	47	4.38887628	72	5.85854586	97	7.76665568
23	2.84762462	48	4.45374754	73	5.96591898	98	7.83600082
24	2.89236342	49	4.4850647	74	6.06881822	99	8.02390378
25	2.9639455	50	4.50072328	75	6.16948052		

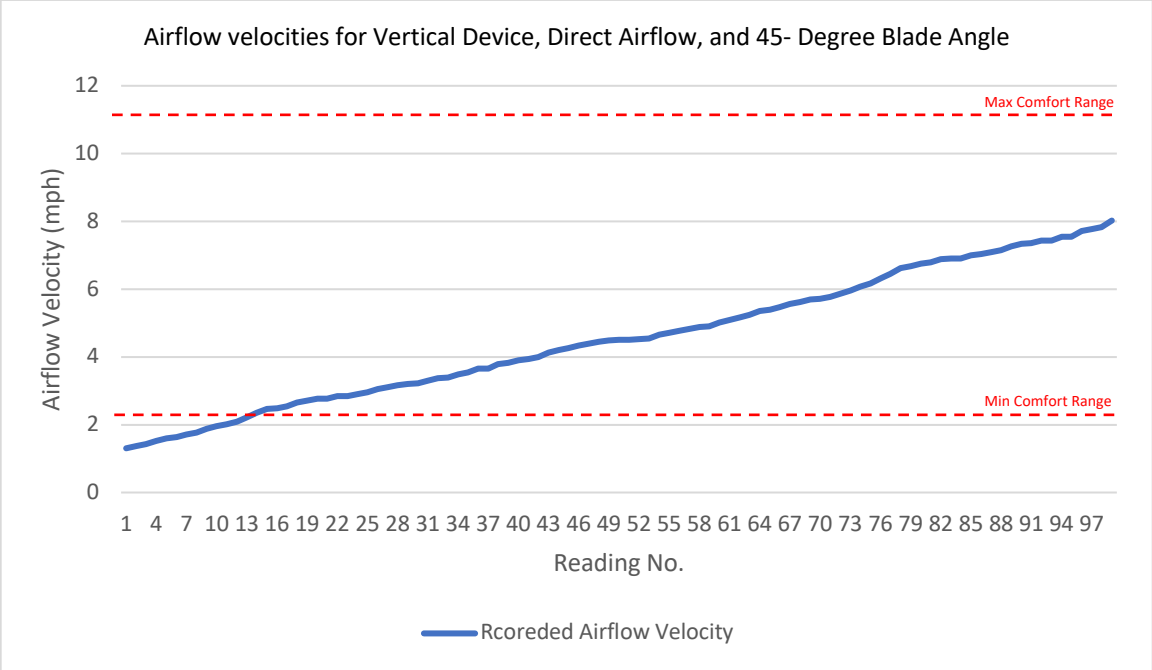

Figure 55: Recorded Data for the Vertically Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle.

6.3.2.2. Horizontally Oriented Mechanical Device

The following experimental setups are for a horizontally oriented mechanical device with 45-degree blade angle. Positioned strategically at the midpoint of the workstation, perpendicular to the occupant location, the mechanical device was applied for three distinct cases: direct upward airflow, direct forward airflow, and direct downward airflow. Each case is described below.

6.3.2.2.1. Direct Upward Airflow

In this scenario, as discussed before in section 6.3.1.2.1, the device was tilted upward at 35-degrees to direct the airflow towards the air velocity transducer. Figure 56 presents a schematic representation of the horizontal mechanical device with direct upward airflow and 45-degree blade angle. The settings for this scenario are presented in Figure 57 and the recorded data are presented in Table 20 and Figure 58.

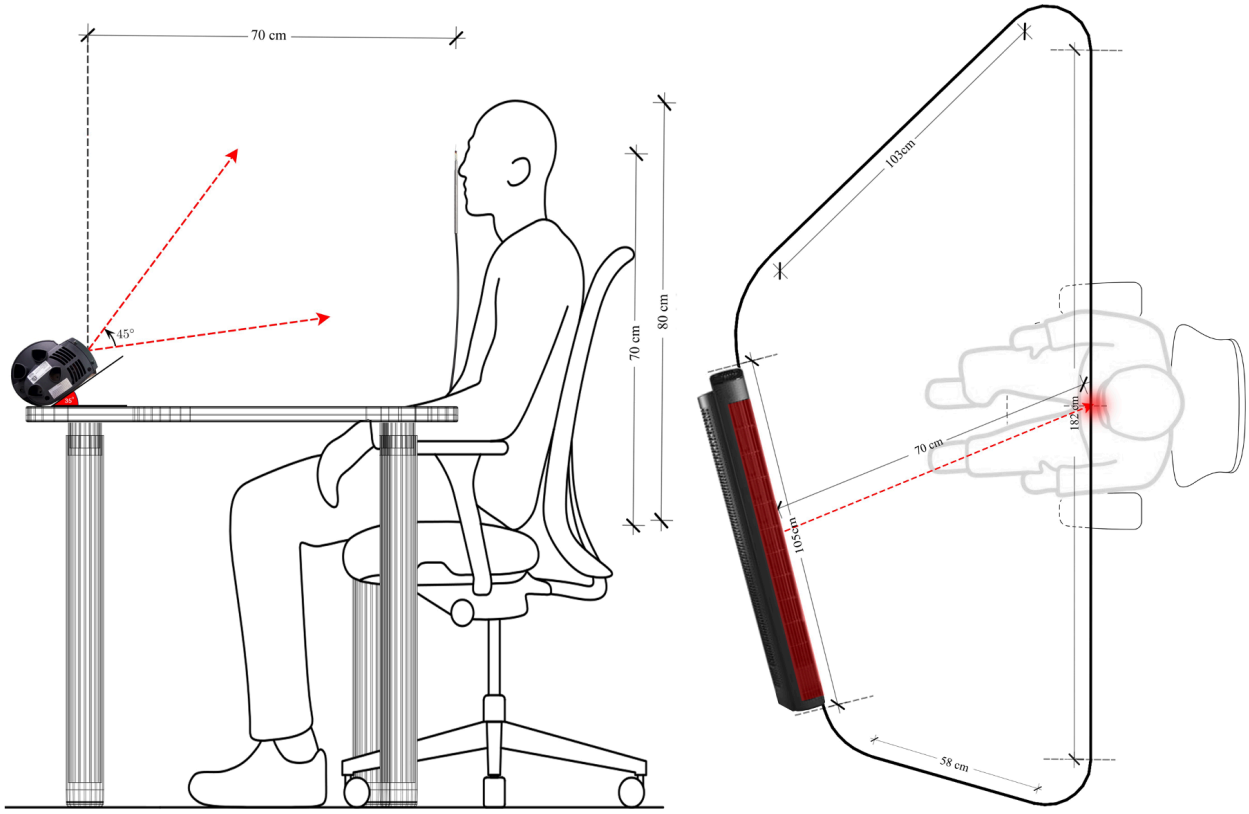

Figure 56: Schematic Representation of the Horizontal Mechanical Device with Direct Upward Airflow and 45-Degree Blade Angle.

Figure 57: Horizontally Oriented Mechanical Device with Direct Upward Airflow and 45-Degree Blade Angle.

Table 20: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Upward Airflow and a 45-Degree Blade Angle.

Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)
1	1.12518082	26	2.34655006	51	3.57463012	76	4.72665422
2	1.30189908	27	2.36220864	52	3.60371034	77	4.78928854
3	1.36005952	28	2.37786722	53	3.6573969	78	4.81165794
4	1.4204569	29	2.40694744	54	3.70884652	79	4.90560942
5	1.37124422	30	2.43379072	55	3.7692439	80	4.9548221
6	1.44506324	31	2.46734482	56	3.88780172	81	5.02864112
7	1.47861734	32	2.51432056	57	3.94148828	82	5.09798626
8	1.53677778	33	2.59932428	58	3.82740434	83	5.18522692

9	1.5994121	34	2.6395892	59	4.01754424	84	5.25233512
10	1.70678522	35	2.7066974	60	3.9705685	85	5.3462866
11	1.77389342	36	2.77156866	61	4.0600461	86	5.41115786
12	1.94166392	37	2.84762462	62	4.13386512	87	5.48721382
13	1.99311354	38	2.8744679	63	4.1942625	88	5.53418956
14	2.0579848	39	2.9415761	64	4.25242294	89	5.65051044
15	2.17206874	40	3.01092124	65	4.29939868	90	5.65274738
16	2.23246612	41	3.02434288	66	4.36874382	91	5.70867088
17	2.32865454	42	3.07131862	67	4.48059082	92	5.94354958
18	2.35549782	43	3.12947906	68	4.71099564	93	5.78696378
19	2.38905192	44	3.19658726	69	5.21654408	94	6.02407942
20	2.40918438	45	3.2547477	70	4.94587434	95	5.84512422
21	2.31970678	46	3.35317306	71	5.5699806	96	6.11579396
22	2.5277422	47	3.3665947	72	4.60362252	97	6.05539658
23	2.33312842	48	3.44936148	73	4.6192811	98	6.11355702
24	2.2928635	49	3.56120848	74	4.63270274	99	6.22764096
25	2.36444558	50	3.52989132	75	4.66849378		

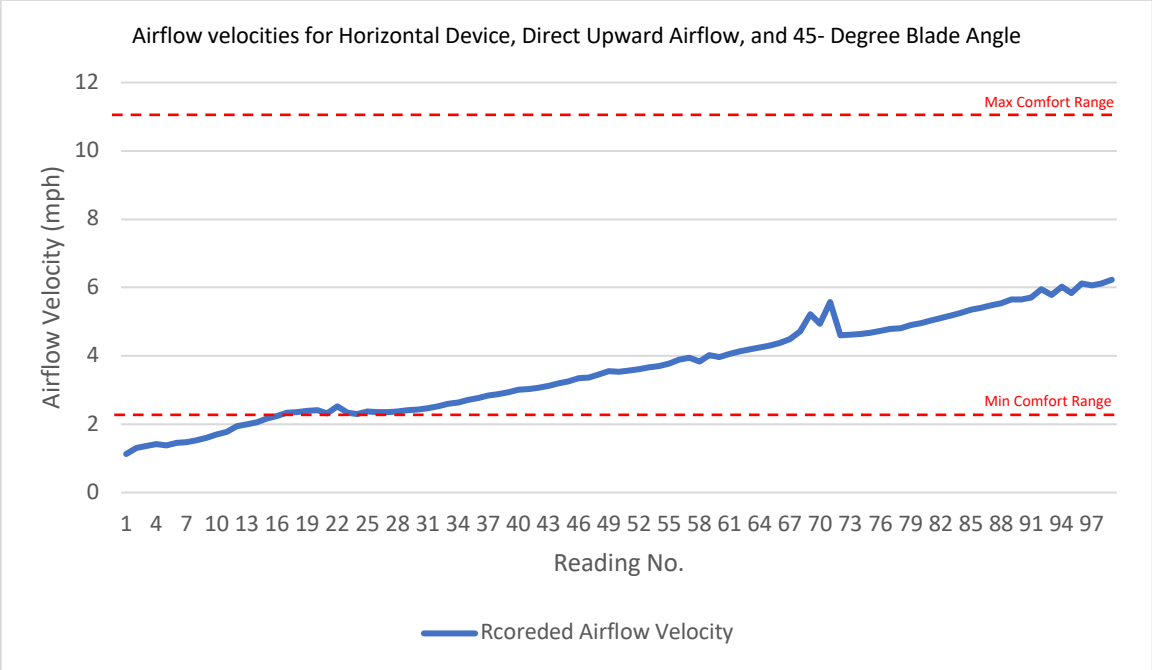

Figure 58: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Upward Airflow and a 45-Degree Blade Angle.

6.3.2.2.2. Direct Forward Airflow

For this experimental scenario the mechanical device was positioned at the level of the occupant's head while aligning with the position of the air velocity transducer. In this arrangement, the device was positioned at a 0-degree tilt angle and set perpendicularly to the air velocity transducer. Figure 59 presents a schematic representation of the horizontal mechanical device with direct forward airflow and 45-degree blade angle. The settings for this scenario are presented in Figure 60 and the recorded data are shown in Table 21 Figure 40.

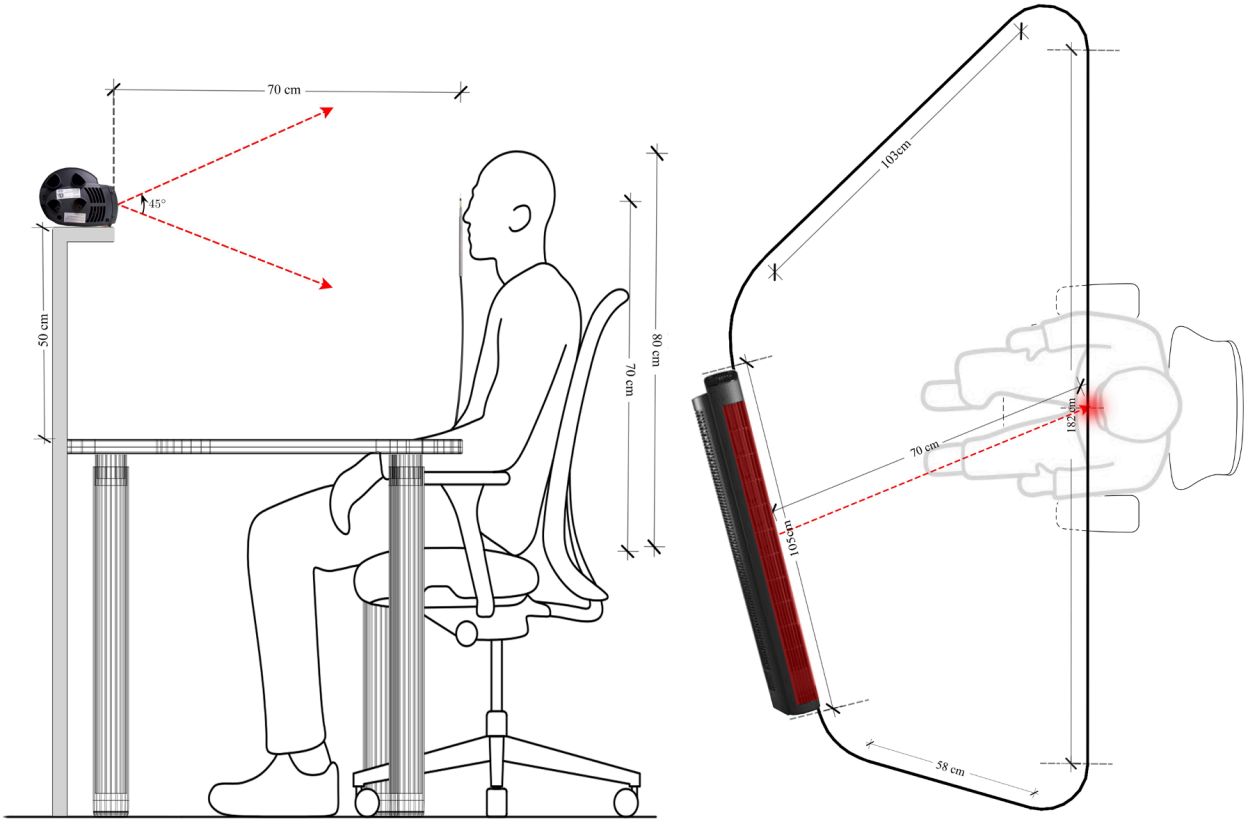

Figure 59: Schematic Representation of the Horizontal Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle.

Figure 60: Horizontally Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle.

Table 21: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Forward Airflow and 45-Degree Blade Angle.

Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)
1	1.41821996	26	2.78722724	51	4.52756656	76	6.01513166
2	1.54125166	27	2.84762462	52	4.55440984	77	6.06658128
3	1.6441509	28	2.9192067	53	4.57230536	78	6.14263724
4	1.72020686	29	2.95499774	54	4.59243782	79	6.21198238
5	1.76941954	30	3.019869	55	4.6192811	80	6.2858014
6	1.82534304	31	3.08921414	56	4.67073072	81	6.39317452
7	1.90810982	32	3.17198092	57	4.70652176	82	6.42672862
8	2.05574786	33	3.29277568	58	4.63717662	83	6.53633868
9	1.99758742	34	3.25922158	59	4.88547696	84	6.68173978
10	2.23022918	35	3.33527754	60	4.75126056	85	6.75779574
11	4.25465988	36	3.40909656	61	4.83850122	86	6.80477148
12	2.14075158	37	3.49186334	62	4.89442472	87	6.85174722
13	2.23022918	38	3.53660214	63	4.95258516	88	6.91438154
14	2.28838962	39	3.61713198	64	5.0107456	89	6.9680681
15	2.31299596	40	3.70660958	65	5.0890385	90	7.04412406

16	2.33089148	41	3.77595472	66	5.20983326	91	7.12241696
17	2.36220864	42	3.82740434	67	5.30602168	92	7.34387402
18	2.37339334	43	3.9593838	68	5.4022101	93	7.2029468
19	2.3935258	44	4.01754424	69	5.58563918	94	7.44677326
20	2.41365826	45	4.00635954	70	5.47826606	95	7.26781806
21	2.55905936	46	4.05780916	71	5.66840596	96	7.493749
22	2.43379072	47	4.13386512	72	5.76906826	97	7.49151206
23	2.6395892	48	4.1830778	73	5.77577908	98	7.54743556
24	2.50089892	49	4.24123824	74	5.87644138	99	7.72191688
25	2.71564516	50	4.50967104	75	5.94354958		

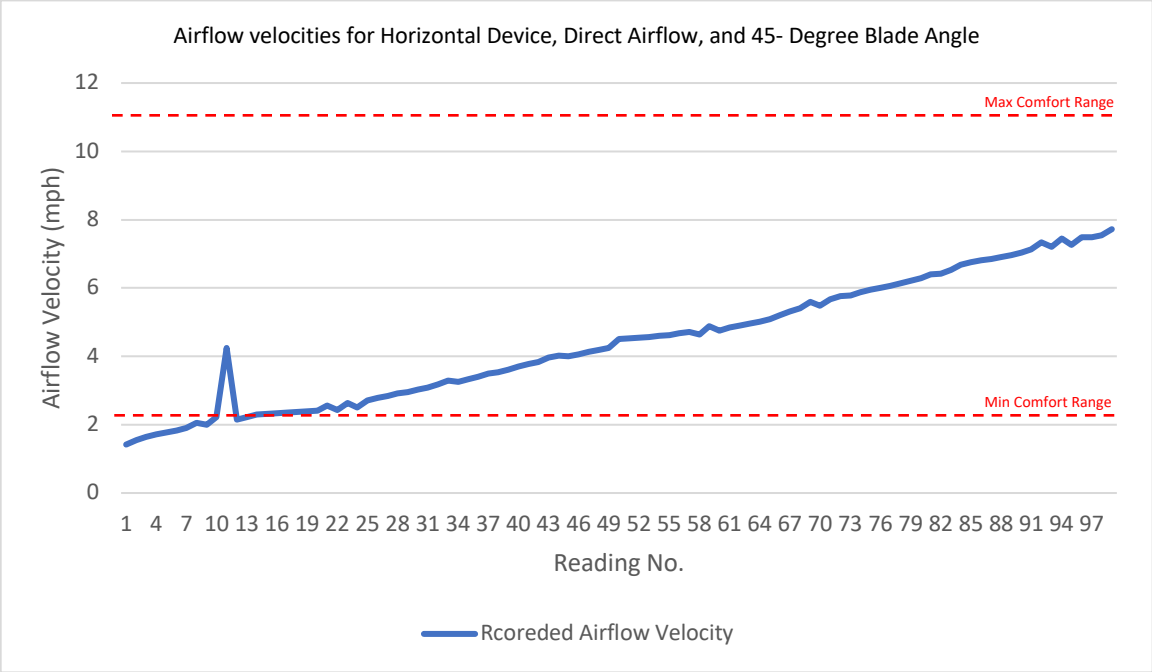

Figure 61: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Forward Airflow and a 45-Degree Blade Angle.

6.3.2.2.3. Direct Downward Airflow

For this scenario, the mechanical device was positioned above the level of the occupants' head. To guide the airflow towards the air velocity transducer, the device was inclined downward at a 35-degree angle. Figure 62 presents a schematic representation of the horizontally oriented mechanical device with direct downward airflow and 45-degree blade angle. The settings for this scenario are presented in Figure 63 and the recorded data are shown in Table 22 and Figure 64.

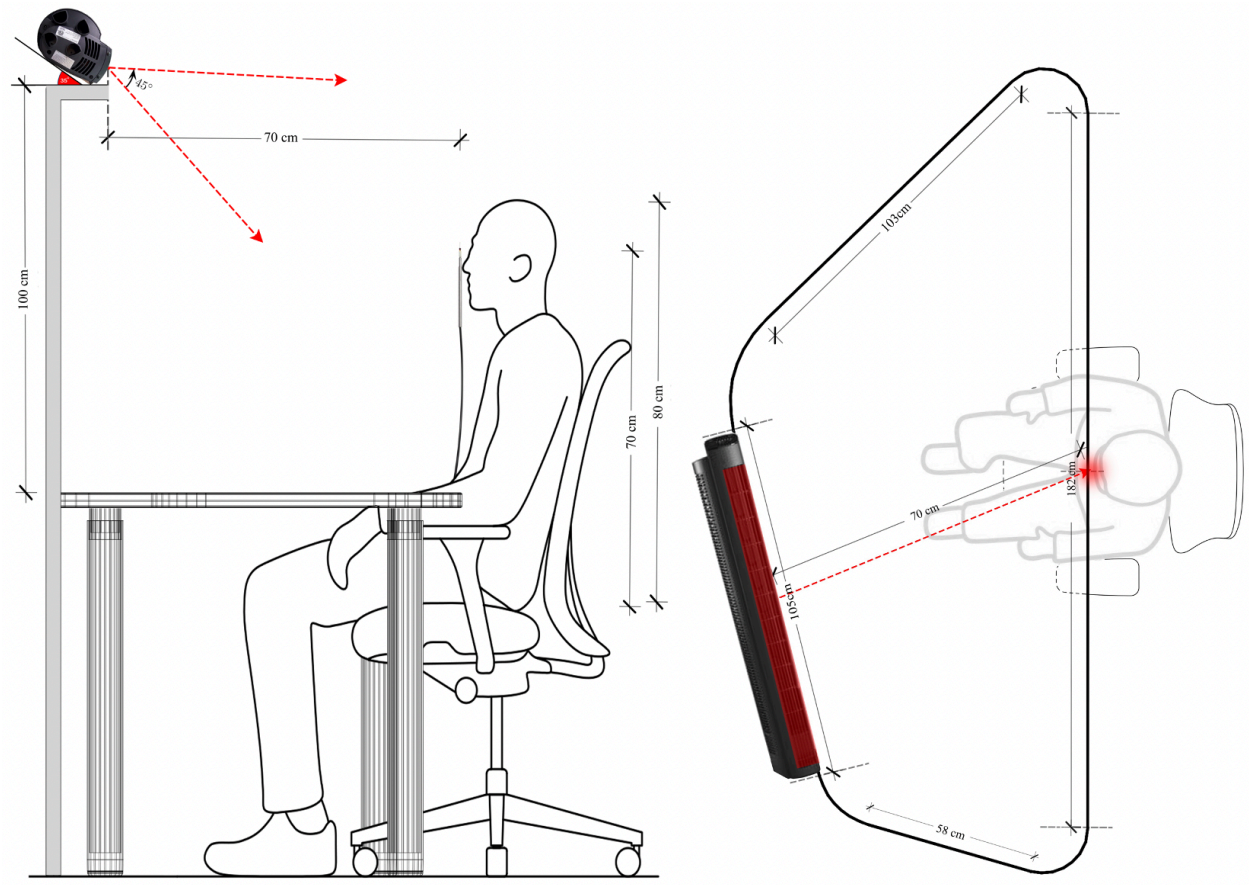

Figure 62: Schematic Representation of the Horizontal Mechanical Device with Direct Downward Airflow and 45-Degree Blade Angle.

Figure 63: Horizontally Oriented Mechanical Device with Direct Downward Airflow and 45-Degree Blade Angle.

Table 22: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Downward Airflow and 45-Degree Blade Angle.

Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)	Reading No.	Airflow Velocity (mph)
1	1.45848488	26	2.98184102	51	4.12268042	76	5.84512422
2	1.48980204	27	3.08474026	52	4.19873638	77	5.86301974
3	1.5099345	28	3.16079622	53	4.24571212	78	5.8831522
4	1.54125166	29	3.22566748	54	4.30387256	79	5.90775854
5	1.57033188	30	3.2883018	55	4.3061095	80	5.93460182
6	1.69112664	31	3.243563	56	4.43808896	81	5.96368204
7	1.73586544	32	3.34646224	57	4.53427738	82	5.97934062
8	1.84100162	33	3.44936148	58	4.35755912	83	6.01065778

9	1.94166392	34	3.5119958	59	4.59467476	84	6.03079024
10	2.0020613	35	3.57015624	60	4.6416505	85	6.08223986
11	2.06245868	36	3.5902887	61	4.73560198	86	6.13816336
12	2.14298852	37	3.61936892	62	4.7646822	87	6.2858014
13	2.19443814	38	3.60818422	63	4.7870516	88	6.21421932
14	2.26825716	39	3.63726444	64	4.86087062	89	6.24777342
15	2.34655006	40	3.6573969	65	4.90113554	90	6.2969861
16	2.31299596	41	3.68871406	66	4.9436374	91	6.41330698
17	2.38681498	42	3.7245051	67	5.06443216	92	6.59226218
18	2.460634	43	3.74016368	68	5.15167282	93	6.4647566
19	2.54116384	44	3.75582226	69	5.24115042	94	6.70187224
20	2.64406308	45	3.77371778	70	5.24338736	95	6.54528644
21	2.77827948	46	3.79385024	71	5.34181272	96	6.74884798
22	2.64630002	47	3.83187822	72	5.46484442	97	6.82490394
23	2.84538768	48	3.8922756	73	5.5699806	98	6.8785905
24	2.68880188	49	4.01083342	74	5.68853842	99	6.99267444
25	2.93262834	50	4.0824155	75	5.85407198		

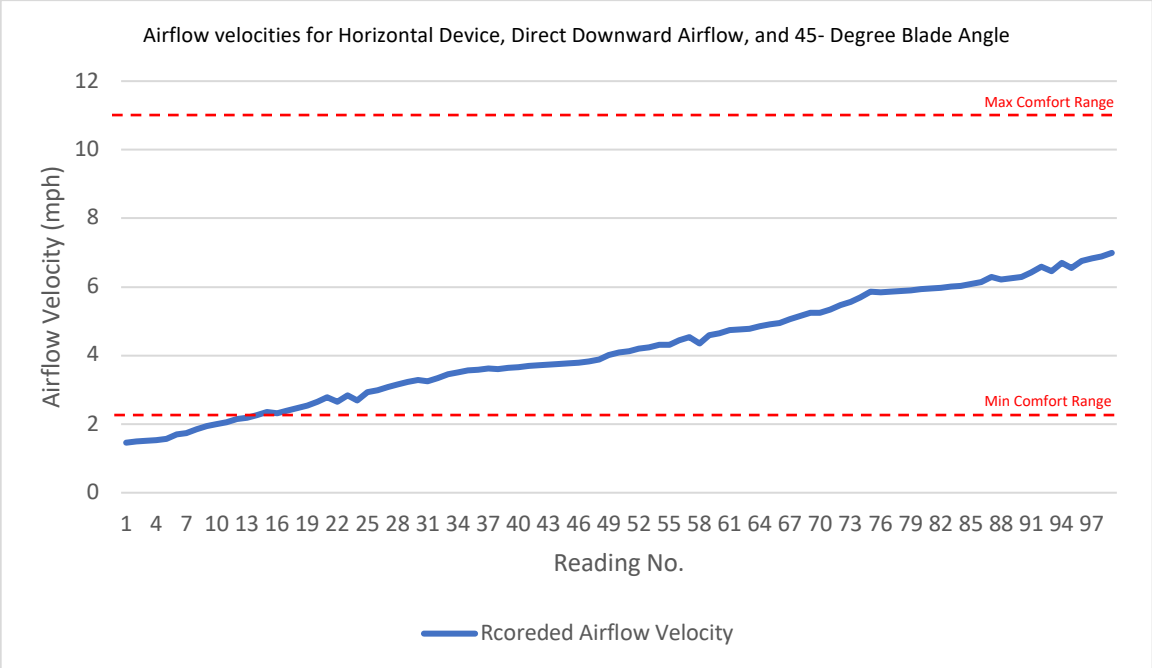

Figure 64: Recorded Data for the Horizontally Oriented Mechanical Device with Direct Downward Airflow and a 45-Degree Blade Angle.

6.4. Data Analysis and Evaluation of the Cases

In the preceding sections, various experimental configurations were explored, each designed to examine the influence of blade angle, mechanical device orientation, and airflow direction on airflow velocities at the location of a seated occupant. This section presents a cross-case analysis, synthesizing the insights gained from the evaluation factors. Evaluations and comparisons were made by considering the interactions in terms of the target natural airflow velocity range, the minimum correlation coefficients between the experimental and target airflow velocities, airflow velocity fluctuations, statistical distribution of the data, and turbulence intensity. An overall assessment of the effectiveness of each experimental configuration is provided to analyze and compare the cases and determine the experimental conditions that best mimic natural airflow patterns.

6.4.1. Evaluation Factor: Natural Airflow Velocity Range

In this evaluation, a comprehensive comparison between the recorded data for the research cases and the established natural airflow velocities comfort range and turbulence intensity was conducted. The primary objective was to determine the level of convergence between the experimental setups and the natural airflow velocities. This assessment aimed to identify cases that closely align with or replicate the natural airflow velocity range and fluctuation, providing crucial insights into their potential to mimic the natural airflow patterns.

To facilitate this analysis, two graphical representations were generated, one for cases featuring 0-degree blade angle and another for those with 45-degree blade angle. These graphs enabled a visual comparison between the recorded data and the natural airflow velocity within the comfort range. Figure 65 presents the airflow velocities for the 0-degree blade angle scenarios and Figure 66 presents the airflow velocities for the 45-degree blade angle scenarios in relation to the comfort range.

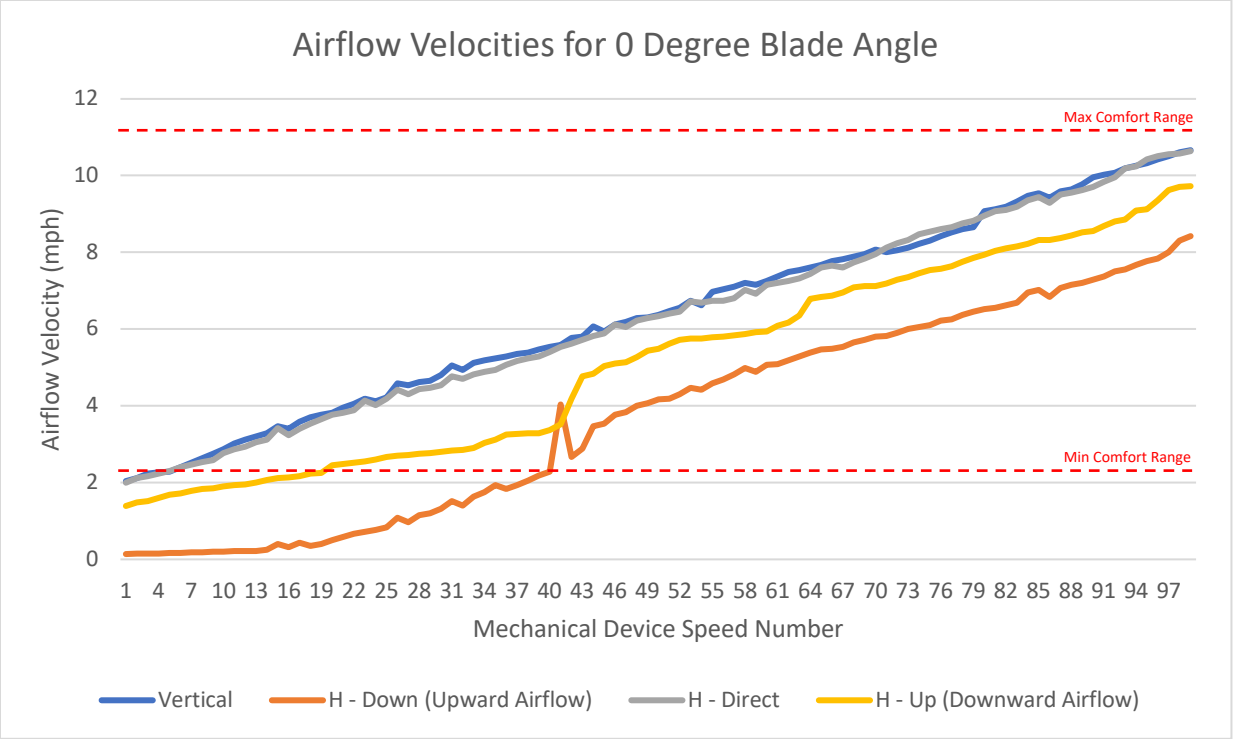

Figure 65: The Recorded Airflow Velocities for the 0-Degree Blade Angle Scenarios.

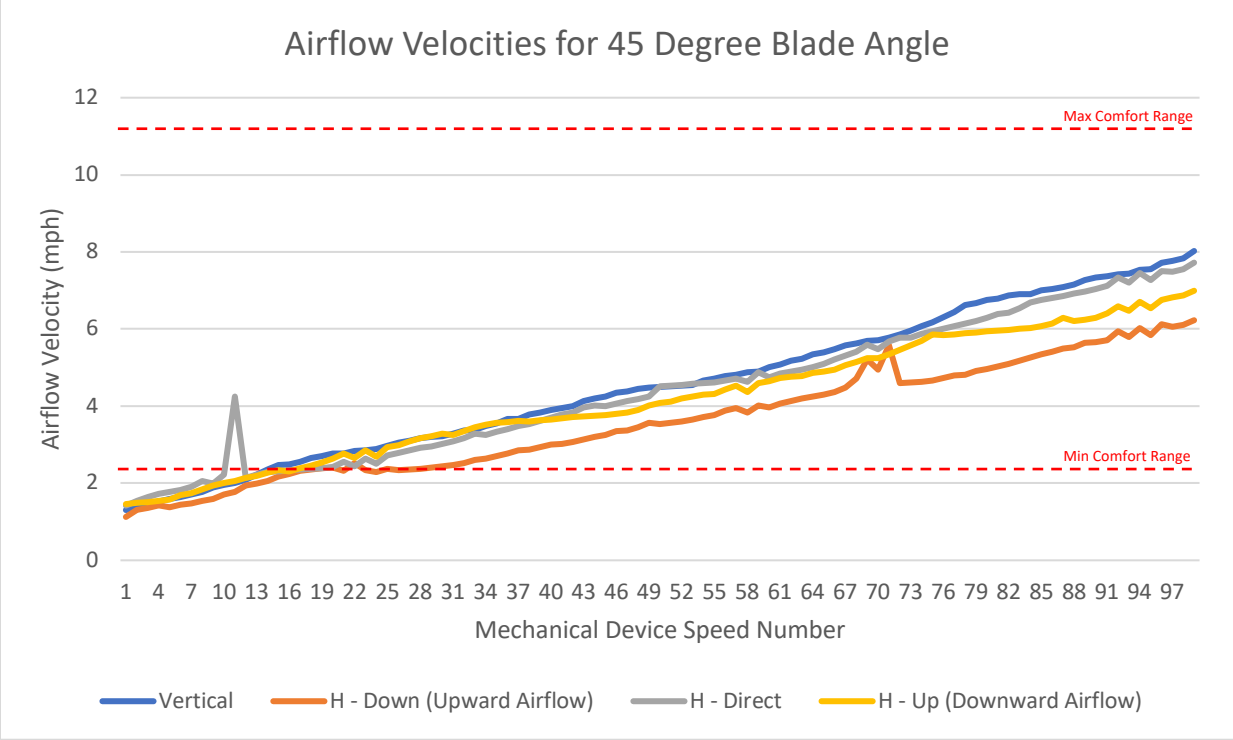

Figure 66: The Recorded Airflow Velocities for the 45-Degree Blade Angle Scenarios.

Upon careful examination of the results and graphs presented in Figure 65 and Figure 66, a notable distinction emerged. The cases with 0-degree blade angle exhibited a closer alignment with the natural airflow comfort range. The airflow in these cases was directed more effectively towards the sensor, resulting in a higher measured airflow speeds at the occupant location. Conversely, the cases with 45-degree blade angle demonstrated slightly less optimal outcomes. In this configuration, airflow distribution at a 45-degree angle led to a reduction in airflow velocity both at the occupant location and at the sensor.

Based on these findings, the 0-degree blade angle cases were analyzed further. Among these cases, two configurations stood out; the vertically oriented mechanical device with direct forward airflow and the horizontally oriented mechanical device with direct forward airflow. These configurations consistently yielded results that mostly fell within the natural airflow comfort range, ranging from the minimum to nearly the maximum natural airflow velocities from the Blacksburg weather file.

Based on this analysis, the vertical and the horizontally oriented mechanical device with direct forward airflow and 0-degree blade angle were determined as the most promising cases. Their capacity to closely replicate the natural airflow velocity range suggested that they were ideal candidates for further analysis.

6.4.2. Evaluation Factor: Minimum Correlation Coefficient

There are quantitative metrics that could be used to compare the airflow measurements at the occupant location to the natural airflow target values including; Pearson Correlation Coefficient, Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). For this research, Pearson Correlation Coefficient was used to compare the results.

This metric measures the degree of the linear relationship between two different variables. In this research, it was used to measure the strength and direction of the linear relationship between the natural airflow target values and the measured airflow at the occupant location. Pearson Correlation Coefficient (r) could be calculated by using this formula:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

Where;

r = correlation coefficient

x_i = values of the x-variable in a sample

$\bar{x}$ = mean of the values of the x-variable

y_i = values of the y-variable in a sample

$\bar{y}$ = mean of the values of the y-variable

According to Pearson Correlation Coefficient, r will range between -1 and 1. The following guideline was used to understand and determine the type of relationship between the data sets:

If r is equal to 0, this indicate that there is no linear relationship between the two data sets.

If r is close to 1 or -1, this indicates that there is a strong linear relationship between the two data sets. Negative value of r indicates a negative linear relationship, while positive value of r indicates a positive linear relationship.

If r is between 0 and 0.7, this indicates that there is a weak to moderate linear relationship between the two data sets. As r gets closer to 1, the strength of the relationship increases.

Determining the minimum correlation coefficient will depend on the requirements and goals of the research. In general, according to statistical analysis, a correlation coefficient less than 0.3 could be considered as a weak correlation. On the other hand, a correlation coefficient between 0.3 and 0.7 could be considered as a moderate correlation, and a correlation coefficient greater than 0.7 could often be considered a strong correlation. Based on this, the minimum value of the correlation coefficient for this research was determined to be 0.7. Any case for which the correlation coefficient is greater than 0.7 would be considered as simulating natural airflow. The case with the largest absolute value of r would be considered as the best case for simulating natural airflow.

The Minimum Correlation Coefficient plays a pivotal role in this research, serving as a critical metric for evaluating the convergence between the experimental cases and the natural airflow target conditions. In this research, understanding the significance of the Minimum Correlation Coefficient lies in its capacity to quantify the degree of the relationship between the

experimental cases and the natural airflow conditions we seek to replicate. This metric serves as a quantitative indicator of how closely our selected cases mimic the natural airflow patterns, providing a foundation for informed decision-making in developing the BLNAS.

The first step in assessing the correlation coefficients was to ensure that the natural airflow data and the data sets from the best test scenarios have the same number of data points. As mentioned in the previous analysis, the Blacksburg natural airflow data set consists of 1252 data points that represent the natural airflow velocities. On the other hand, each of the two test scenarios consisted of 99 data points. By analyzing the Blacksburg data, it was noticed that there was a repetition in some data points. By removing the repeated data points, it was found that the Blacksburg data mainly consisted of only 38 data points that were repeated. These 38 data points fall within the natural airflow velocity comfort range from 2.46 to 10.96 mph. These 38 data points were used as a shortlist for the Blacksburg natural airflow data set. To leverage the Minimum Correlation Coefficient effectively, the data sets were used. The first step in assessing the correlation coefficient involved returning to the natural airflow-data set for Blacksburg, comprising 1280 data points. Within this data set, 38 duplicated data points were identified. By appending the upper and lower boundaries of the natural comfort airflow range, this list was transformed into a condensed, 40-point data set.

This shortlist was organized in descending order as shown in Table 23 and used as a reference point for natural airflow velocities. Subsequently, the measured data for the two most promising cases: the vertical and horizontally oriented mechanical devices with direct forward airflow, featuring 0-degree blade angles were used. The measurements that closely approximated the values found in the natural airflow shortlist were selected and presented in Table 23 besides their equivalent speed settings on the mechanical device. It's important to highlight that the highest 3 two values of natural airflow velocities were beyond the mechanical device capacity. For that, their values were left empty as shown in Table 23.

Table 23: Shortlist of Natural Airflow Velocities, the Cases' Closest Speeds, and the Corresponding Speed Settings.

Corresponding Speed No. on Fan			Closest Velocities (mph)	
Vertical	**Horizontal**	**Natural Airflow Rounded Velocities (mph)**	**Vertical**	**Horizontal**
-	-	10.96	-	-
-	-	10.74	-	-
97	96	10.51	10.52	10.51
94 or 95	94	10.29	10.26 or 10.32	10.24
92	92 or 93	10.07	10.08	9.96 or 10.20
89	91	9.84	9.78	9.84
87 or 88	89	9.62	9.60 or 9.64	9.62
84	86	9.40	9.42	9.44
82	83	9.17	9.2	9.18
80	80	8.95	9.07	8.95
79	78	8.72	8.66	8.75
77	74 or 75	8.50	8.53	8.48 or 8.53
72	71	8.05	8.06	8.13
67	69	7.83	7.82	7.84
64	67	7.61	7.6	7.61
61	63 or 64	7.38	7.37	7.32 or 7.43
58	60	7.16	7.16	7.16
55	58	6.93	6.98	6.92
54	54	6.71	6.75	6.72
51	52	6.49	6.47	6.46
48	49	6.26	6.28	6.28
46	47	6.04	6.11	6.06
43	44	5.82	5.81	5.82
41	42	5.59	5.59	5.62
38	40	5.37	5.39	5.41
33	37	5.14	5.12	5.17

31	35	4.92	4.94	4.94
29	31	4.70	4.65	4.71
26	29	4.47	4.54	4.48
25	26	4.25	4.23	4.3
22	23	4.03	4.06	4.02
20	21	3.80	3.83	3.83
17	18	3.58	3.59	3.53
15	16 or 17	3.36	3.4	3.41 OR 3.41 too
12	14	3.13	3.12	3.12
10	11 or 12	2.91	2.87	2.88 or 2.94
8	9 or 10	2.68	2.64	2.59 or 2.77
6	7	2.46	2.41	2.47

The final selected measurements are presented in Table 24 and Figure 67. Because again the two highest values were beyond the capacity of the mechanical device, their values were filled by 0. Because these two values repeated only 5 times in the full Blacksburg data set, they could be removed later.

Table 24: Airflow Velocities for Target Natural Case and the Two Experimental Cases.

Data Point No.	Natural Airflow Velocity (mph)	Vertical – Direct Airflow Velocity (mph)	Horizontal – Direct Airflow Velocity (mph)
1	10.96	0	0
2	10.74	0	0
3	10.51	10.52	10.51
4	10.29	10.26	10.24
5	10.07	10.08	9.96
6	9.84	9.78	9.84
7	9.62	9.6	9.62
8	9.4	9.42	9.44
9	9.17	9.2	9.18
10	8.95	9.07	8.95

11	8.72	8.66	8.75
12	8.5	8.53	8.48
13	8.05	8.06	8.13
14	7.83	7.82	7.84
15	7.61	7.6	7.61
16	7.38	7.37	7.32
17	7.16	7.16	7.16
18	6.93	6.98	6.92
19	6.71	6.75	6.72
20	6.49	6.47	6.46
21	6.26	6.28	6.28
22	6.04	6.11	6.06
23	5.82	5.81	5.82
24	5.59	5.59	5.62
25	5.37	5.39	5.41
26	5.14	5.12	5.17
27	4.92	4.94	4.94
28	4.7	4.65	4.71
29	4.47	4.54	4.48
30	4.25	4.23	4.3
31	4.03	4.06	4.02
32	3.8	3.83	3.83
33	3.58	3.59	3.53
34	3.36	3.4	3.41
35	3.13	3.12	3.12
36	2.91	2.87	2.88
37	2.68	2.64	2.59
38	2.46	2.41	2.47

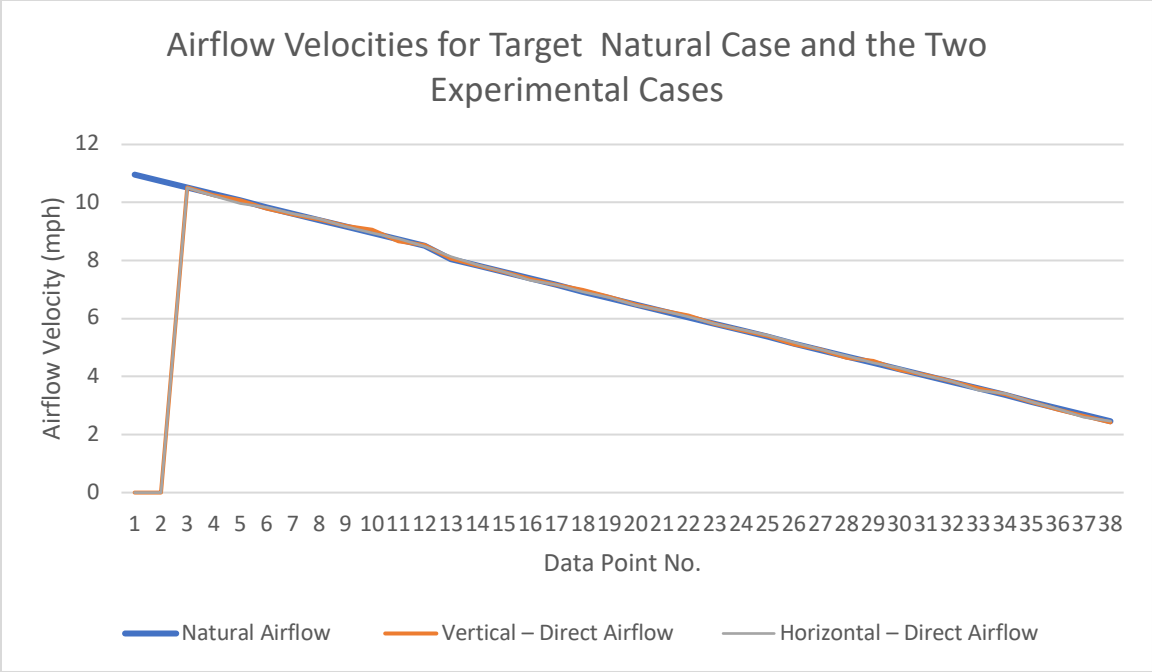

Figure 67: Airflow Velocities for Target Natural Case and the Two Experimental Cases

The data presented in Table 24 and Figure 58 were used to restructure the 1252 data points from the Blacksburg weather file. Excel functions were employed to generate these new data sets. For this, an IF command was used as shown below. A sample of the full data sets for the natural case from the weather file and the two best experimental cases are presented in Table 25. The Full generated data sets are available in Appendix B.

For the vertically oriented case, the IF statement shown below was used to restructure the full data set for the vertical case;

=IF(A1=10.96, 0, IF(A1=10.74, 0, IF(A1=10.51, 10.52, IF(A1=10.29, 10.26, IF(A1=10.07, 10.08, IF(A1=9.84, 9.78, IF(A1=9.62, 9.60, IF(A1=9.40, 9.42, IF(A1=9.17, 9.2, IF(A1=8.95, 9.07, IF(A1=8.72, 8.66, IF(A1=8.50, 8.53, IF(A1=8.05, 8.06, IF(A1=7.83, 7.82, IF(A1=7.61, 7.60, IF(A1=7.38, 7.37, IF(A1=7.16, 7.16, IF(A1=6.93, 6.98, IF(A1=6.71, 6.75, IF(A1=6.49, 6.47, IF(A1=6.26, 6.28, IF(A1=6.04, 6.11, IF(A1=5.82, 5.81, IF(A1=5.59, 5.59, IF(A1=5.37, 5.39, IF(A1=5.14, 5.12, IF(A1=4.92, 4.94, IF(A1=4.70, 4.65, IF(A1=4.47, 4.54, IF(A1=4.25, 4.23, IF(A1=4.03, 4.06, IF(A1=3.80, 3.83, IF(A1=3.58, 3.59, IF(A1=3.36, 3.40, IF(A1=3.13, 3.12, IF(A1=2.91, 2.87, IF(A1=2.68, 2.64, IF(A1=2.46, 2.41,"")))))))

IF(A1=8.72, 8.75, IF(A1=8.50, 8.48, IF(A1=8.05, 8.13, IF(A1=7.83, 7.84, IF(A1=7.61, 7.61, IF(A1=7.38, 7.32, IF(A1=7.16, 7.16, IF(A1=6.93, 6.92, IF(A1=6.71, 6.72, IF(A1=6.49, 6.46, IF(A1=6.26, 6.28, IF(A1=6.04, 6.06, IF(A1=5.82, 5.82, IF(A1=5.59, 5.62, IF(A1=5.37, 5.41, IF(A1=5.14, 5.17, IF(A1=4.92, 4.94, IF(A1=4.70, 4.71, IF(A1=4.47, 4.48, IF(A1=4.25, 4.3, IF(A1=4.03, 4.02, IF(A1=3.80, 3.83, IF(A1=3.58, 3.53, IF(A1=3.36, 3.41, IF(A1=3.13, 3.12, IF(A1=2.91, 2.88, IF(A1=2.68, 2.59, IF(A1=2.46, 2.47,"")))))))

9.17	9.2	9.18
10.29	10.26	10.24
8.05	8.06	8.13
9.17	9.2	9.18
10.29	10.26	10.24
3.36	3.4	3.41
8.05	8.06	8.13
5.59	5.59	5.62
3.36	3.4	3.41
4.47	4.54	4.48
5.59	5.59	5.62
5.59	5.59	5.62
10.29	10.26	10.24
8.05	8.06	8.13
10.29	10.26	10.24
9.17	9.2	9.18
5.59	5.59	5.62

To determine the Minimum Correlation Coefficient, the following formula was employed in Excel:

Minimum Correlation Coefficient (ρ) = CORREL(Natural Airflow Velocities, Best Case Velocities)

The calculated the Minimum Correlation Coefficients for the vertical and horizontal cases, are presented in Table 26, and were found to be 0.939 and 0.938, respectively. These correlation coefficients are relatively high indicating a strong relationship between each of the two experimental cases and the target natural airflow patterns. This supports the proposition that these two BLNAS scenarios are effective in replicating the natural airflow conditions in the indoor environments.

Table 26: The Calculated Minimum Correlation Coefficient for the Two Best Cases.

Vertical Correlation Coefficient	Horizontal Correlation Coefficient
0.939197942	0.93896327

6.4.3. Evaluation Factor: Airflow Velocity Fluctuations

In the quest to optimize indoor airflow patterns and mimic natural airflow, it was important to consider both the velocity as well as the fluctuation of the airflow inherent to natural airflow. These fluctuations represent the dynamic and ever-changing character of natural air movement over short periods of time. By closely examining these fluctuations, we gain valuable insights into the behavior of natural airflow while allowing for the replication of these conditions with the BLNAS.

To assess and replicate these airflow velocity fluctuations, a data-driven analysis was undertaken. For this, the first step involved creating three graphical representations: one depicting the natural airflow velocity fluctuations from the Blacksburg weather file as shown in Figure 68 and two other plots illustrating the fluctuations for the two most promising experimental cases; the vertical and horizontally oriented mechanical devices with direct forward airflow and 0-degree blade angles which are presented in Figure 69 and Figure 70, respectively.

These three graphs were then compared by overlaying them onto a fourth graph, which is shown in Figure 71. The degree of similarity between the fluctuations for the data from the Blacksburg weather data and those from the two best cases were observed. As shown in Figure 71, with the exception of five data points the majority of data points from the best two experimental cases closely matched the natural fluctuations. For those five data points the target natural airflow velocities exceeded the maximum capability of the mechanical device.

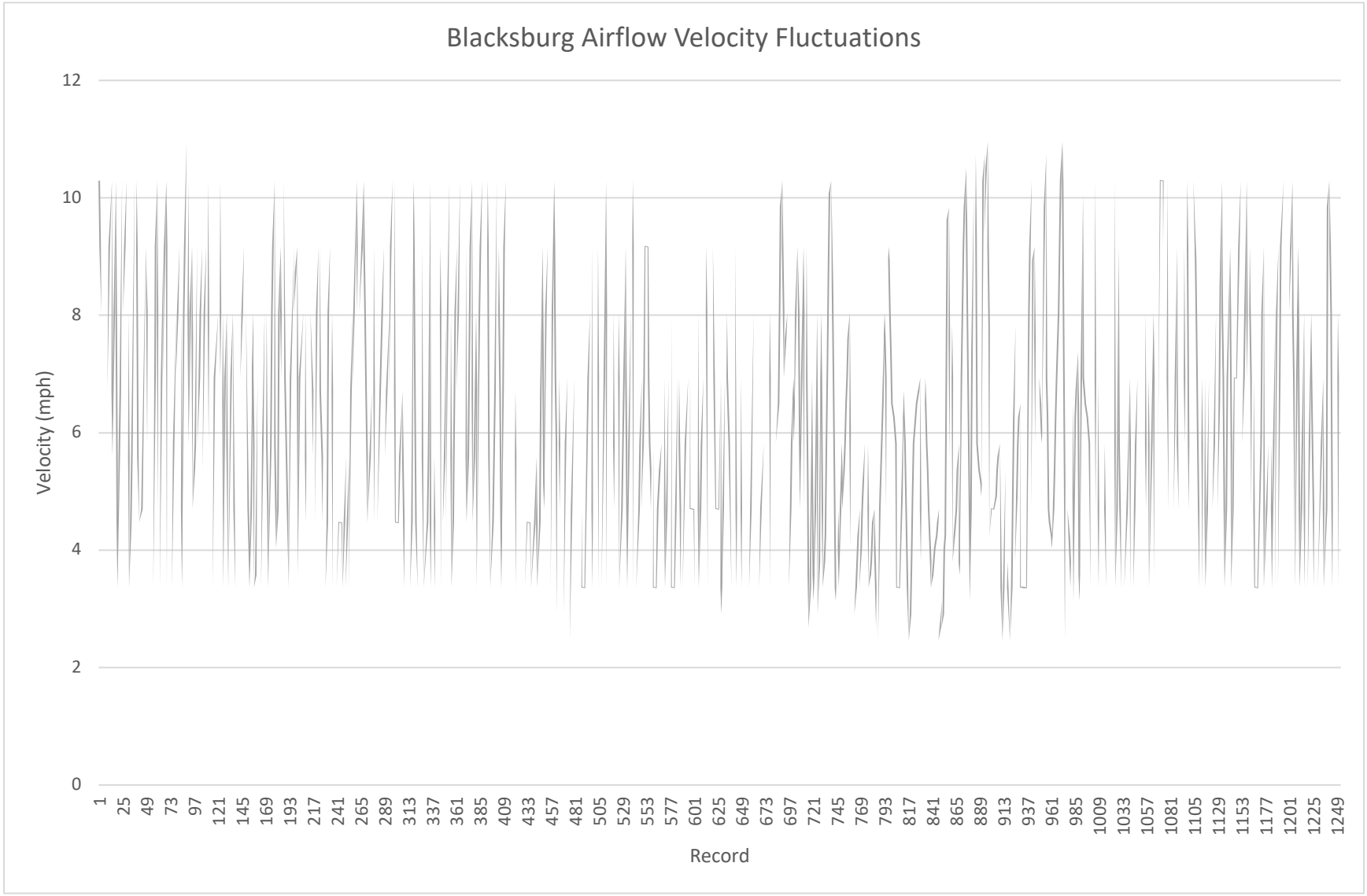

Figure 68: Blacksburg Natural Airflow Velocity Fluctuations.

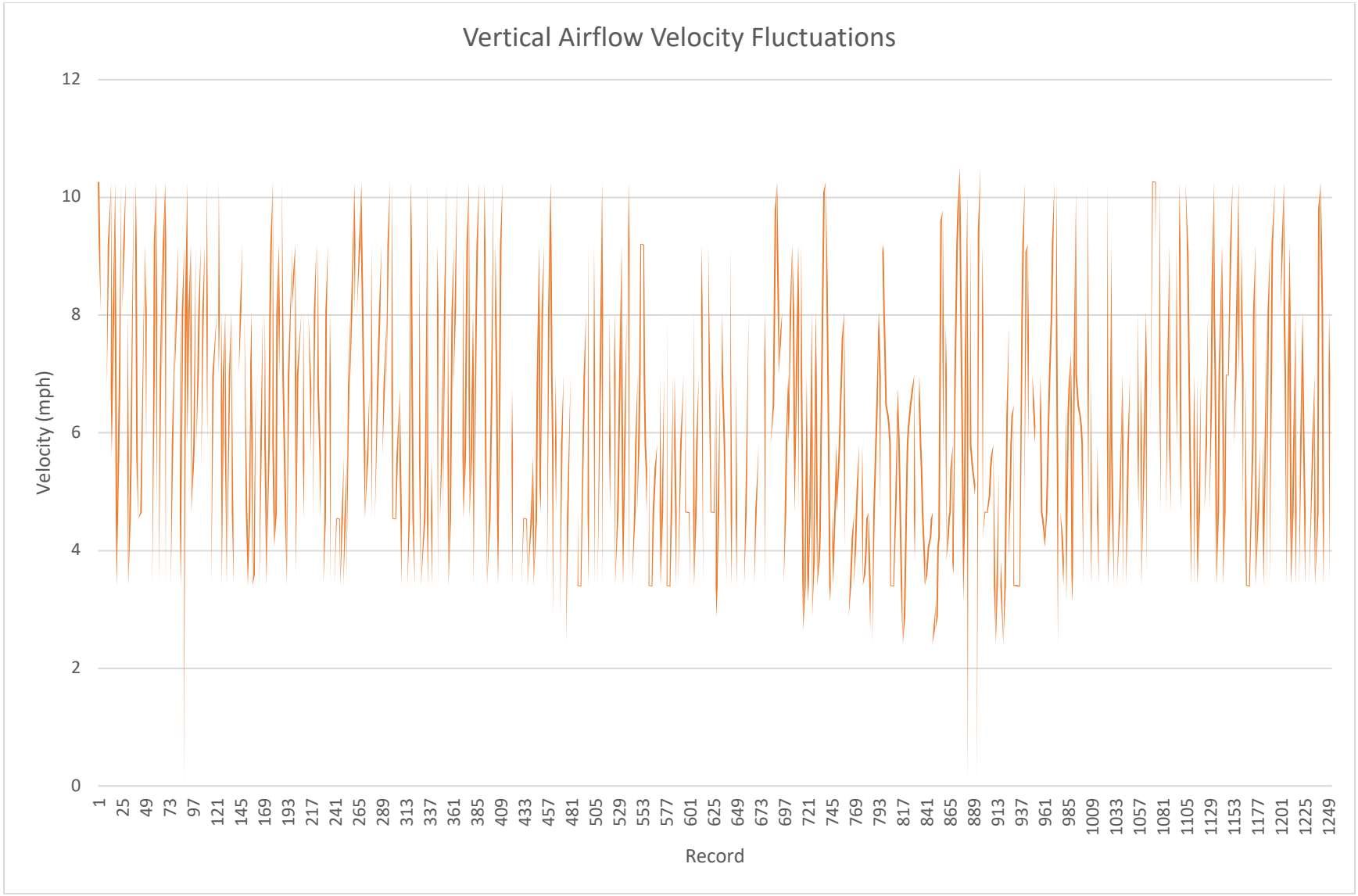

Figure 69: Vertical Airflow Velocity Fluctuations.

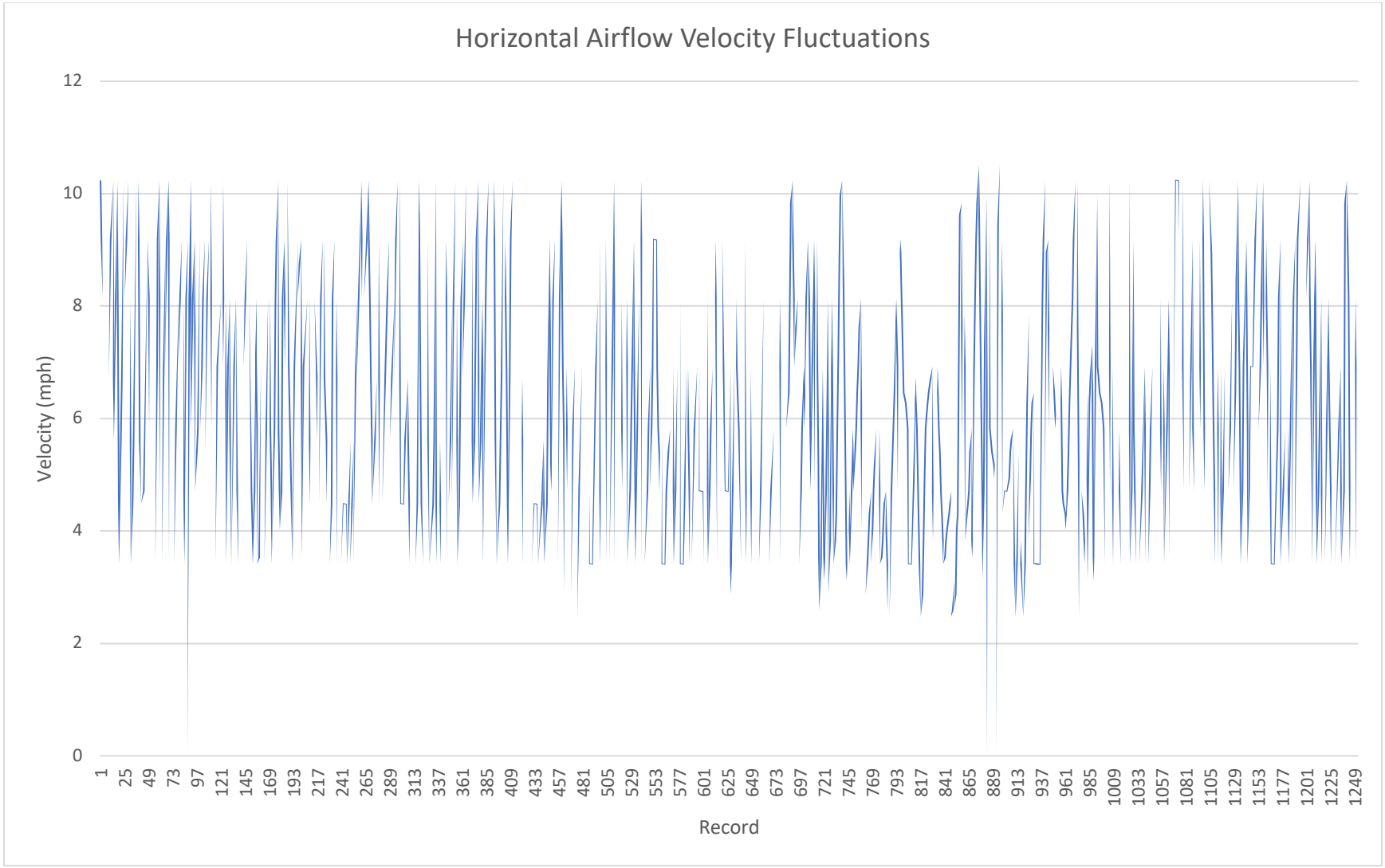

Figure 70: Horizontal Airflow Velocity Fluctuations.

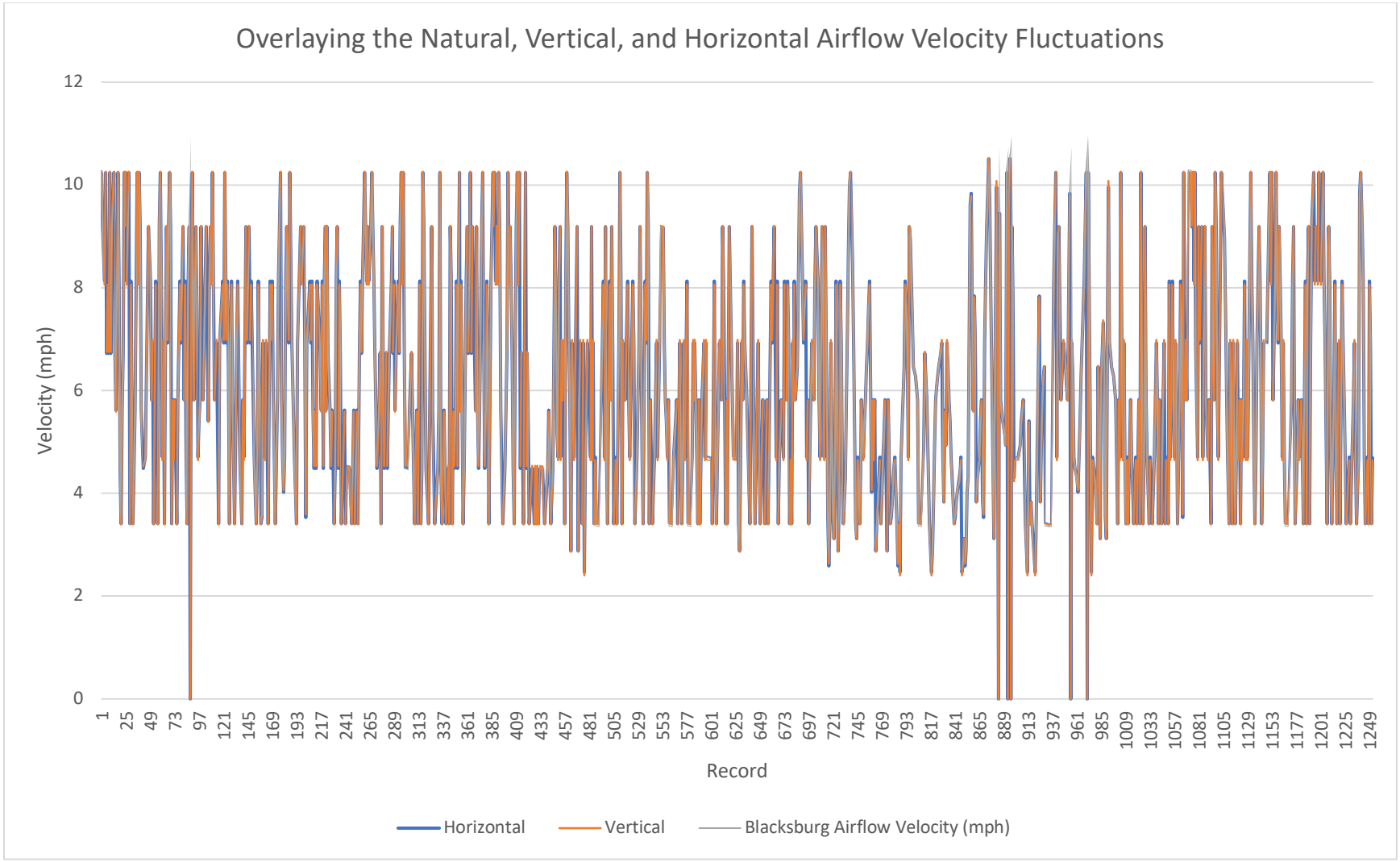

Figure 71: Overlaying the Natural, Vertical, and Horizontal Airflow Velocity Fluctuations.

Based on this analysis, the interpretation of the data suggests that these two experimental cases closely mimic the desired natural airflow velocity fluctuations.

6.4.4. Evaluation Factor: Turbulence Intensity

Turbulence intensity (TI) is a measure of the variability and fluctuations in airflow velocities. TI encapsulates the dynamic behavior of air movement, highlighting instances of turbulence and deviation from laminar flow. The understanding of TI is essential in the quest to replicate natural airflow patterns. For the purpose of this research, this factor was used to assess the turbulence characteristics of the airflow for each BLNAS configuration and its comparison to the natural airflow TI.

To assess TI, an analysis was conducted where three graphical representations were generated; one illustrating the natural TI patterns from the Blacksburg data, which is presented in Figure 72, and two others showing the TI for the two most promising experimental cases; the vertical and horizontally oriented mechanical devices with direct forward airflow and 0-degree blade angles, which are shown in Figure 73 and Figure 74, respectively.

These TI graphs were then compared. The goal was to identify the degree of similarity and difference between the natural TI and those of the best experimental cases. For this an overlay graph was created to facilitate this comparison as shown in Figure 75.

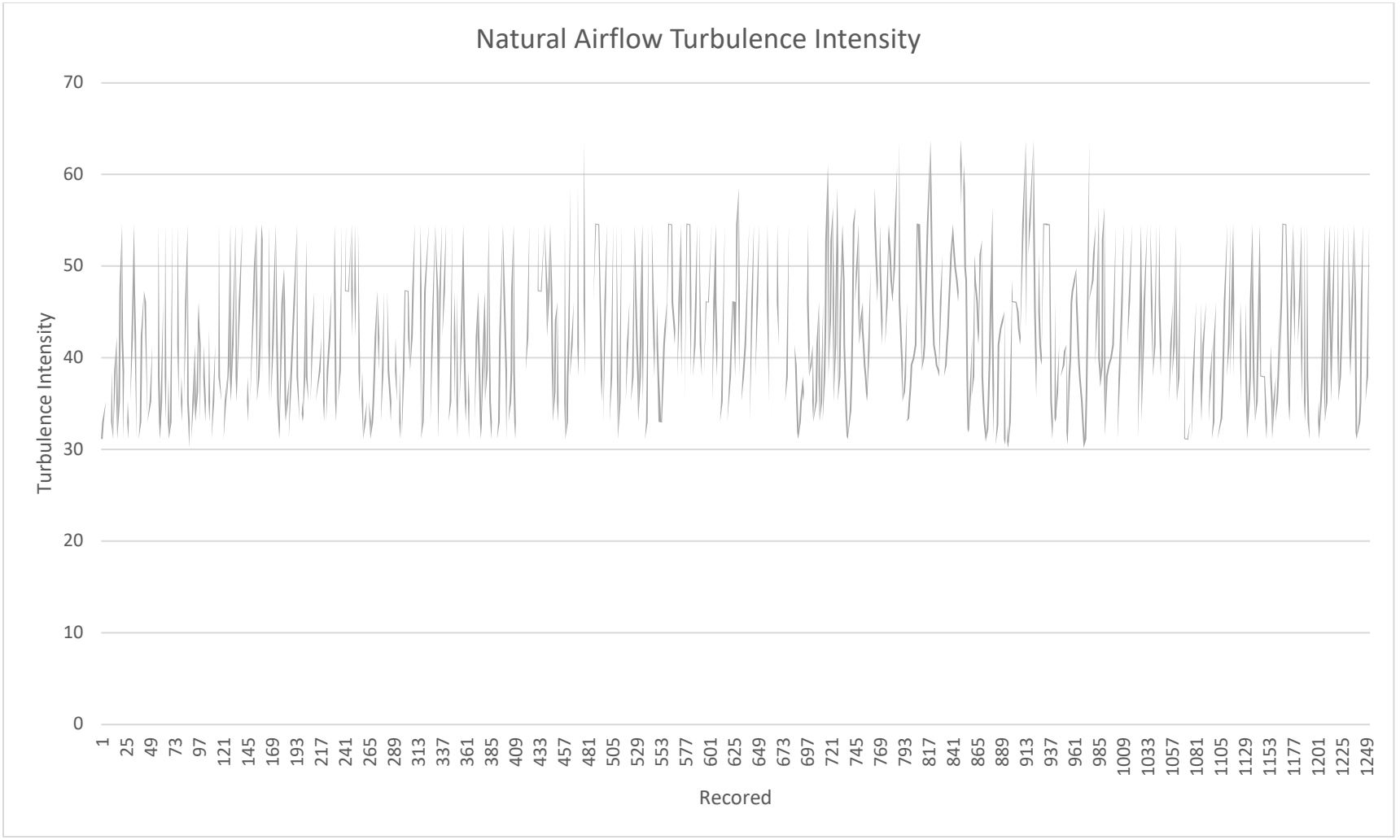

Figure 72: Natural Airflow Turbulence Intensity.

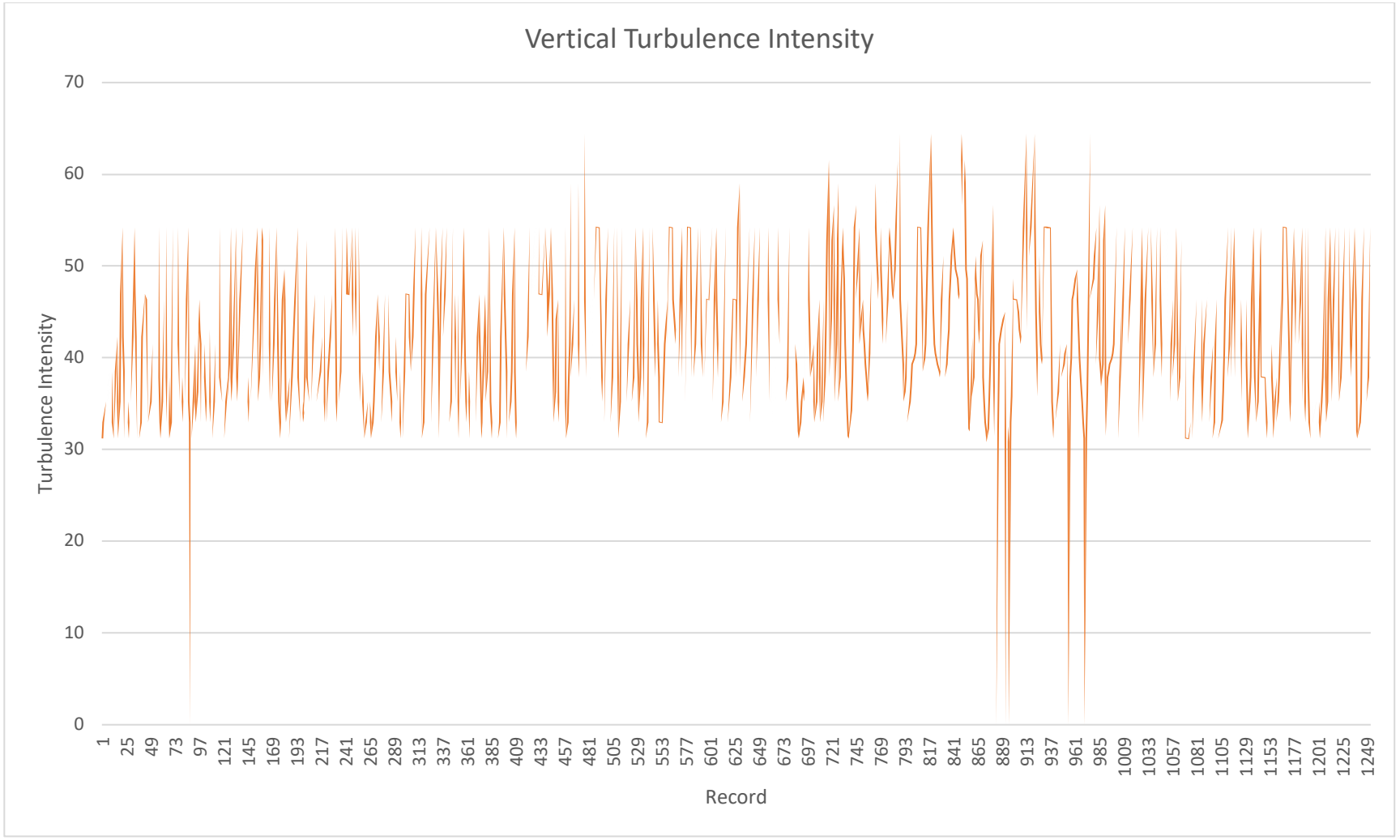

Figure 73: Vertical Turbulence Intensity.

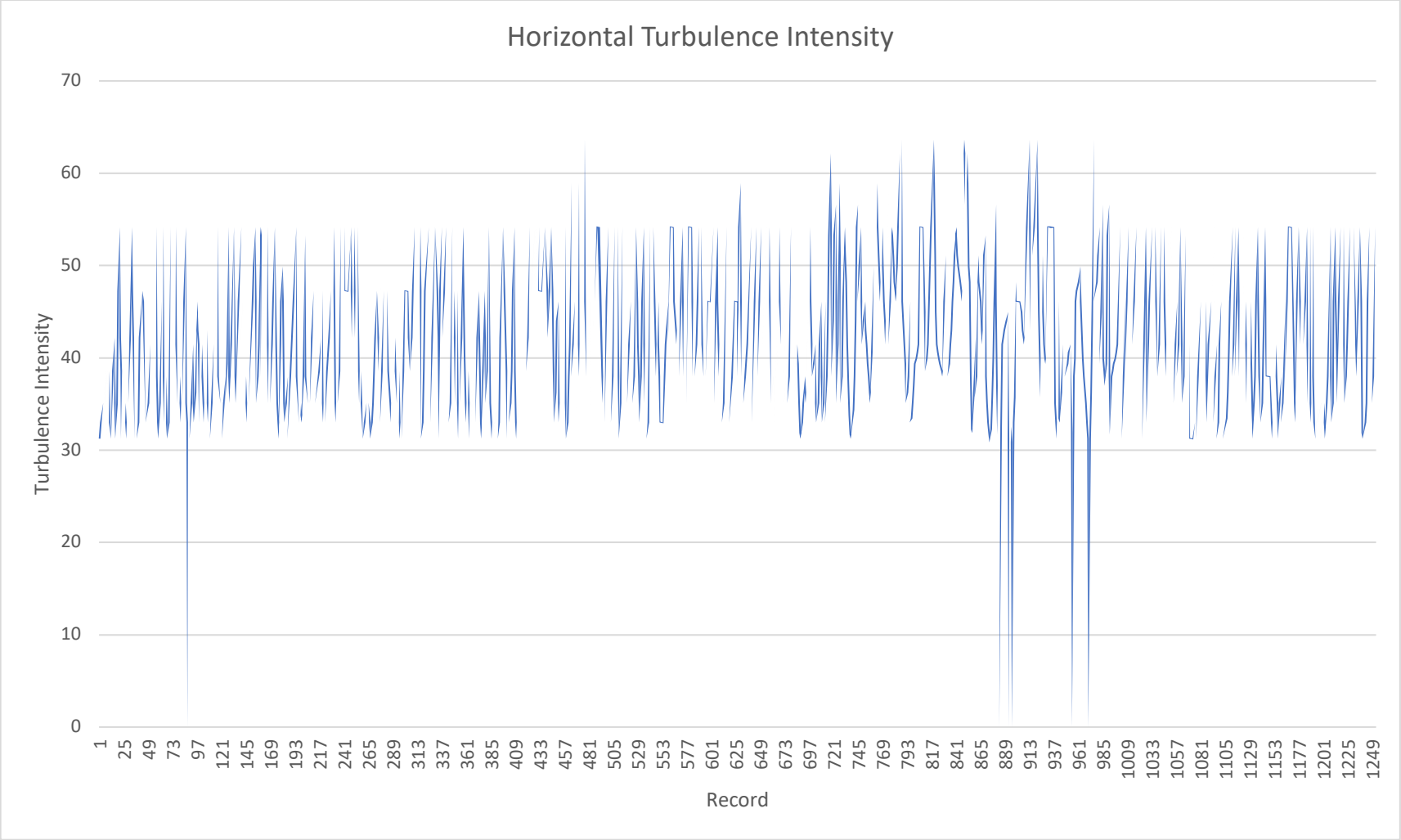

Figure 74: Horizontal Turbulence Intensity.

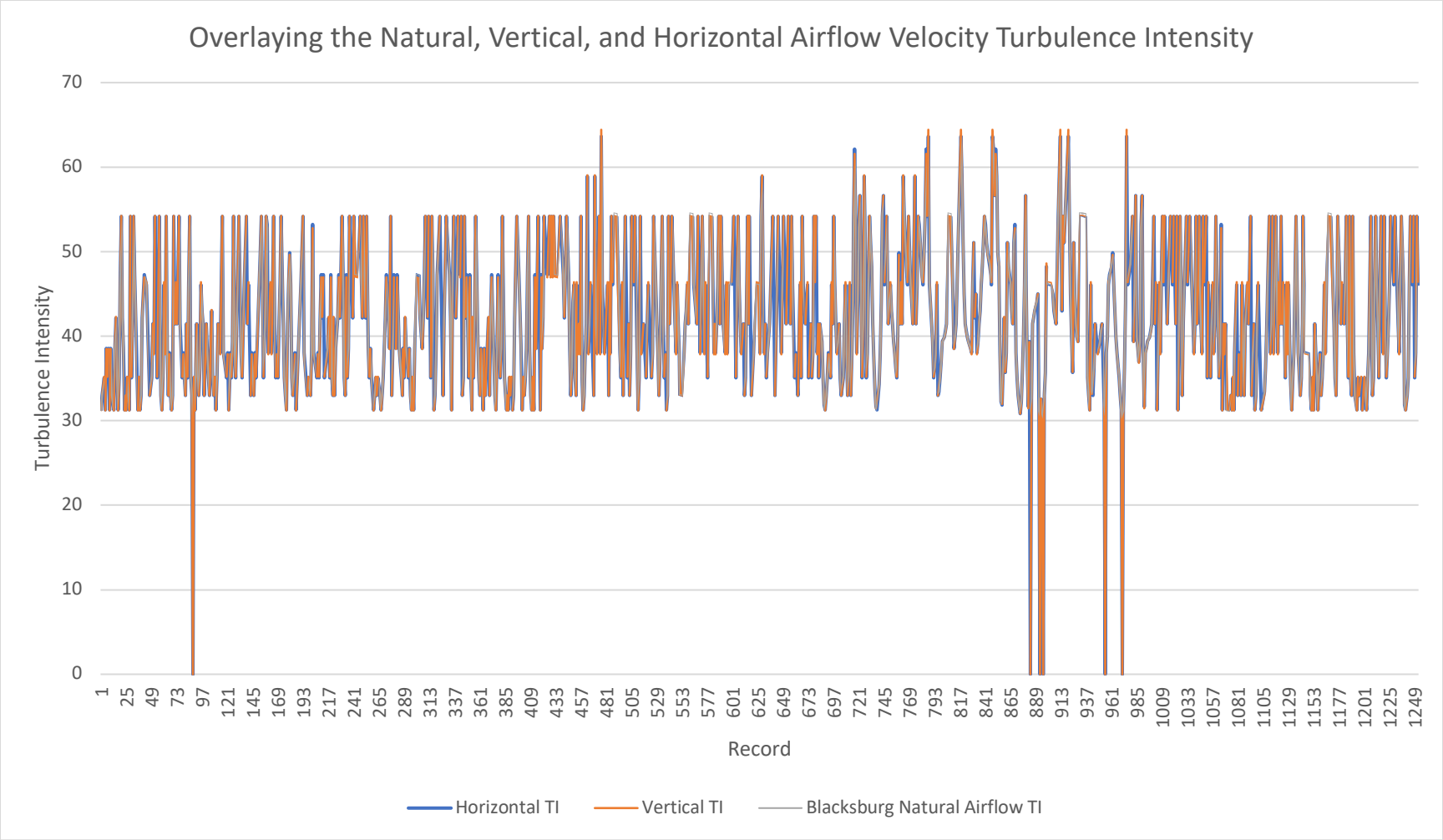

Figure 75: Overlaying the Natural, Vertical, and Horizontal Airflow Velocity Turbulence Intensity.

Through the TI analysis, challenges similar to previous evaluations were encountered. Specifically, five data points in each case fell outside the norm due to exceeding the mechanical device's operational limits. As a result, these data points were recorded as 0, causing the TI to register at 0 as well whereas the rest of the data was mostly similar to the natural airflow TI as presented in Figure 75.

In conclusion, this analysis underscores the potential of these selected cases to effectively replicate TI patterns found in natural airflow. While minor deviations occurred due to limits of the mechanical device, the overall alignment between the two best experimental cases and the target natural TI indicates that the BLNAS does simulate the natural airflow.

6.4.5. Evaluation Factor: Normal Distribution

Another consideration when trying to emulate natural airflow patterns is the statistical distribution of the data. The natural airflow patterns, as determined from the Blacksburg weather data, show normal distribution. This research aims to replicate this distribution with the BLNAS.

To assess and replicate the distribution characteristics, an analytical methodology was employed. The analysis included three graphical representations: one showing the natural airflow velocity distribution from the Blacksburg weather file, which is presented in Figure 76, and two other plots illustrating the distribution for the two most promising experimental cases; the vertical and horizontally oriented mechanical devices with direct forward airflow and 0-degree blade angle, which are presented in Figure 77 and Figure 78, respectively.

These three distribution plots presented in Figures 76, 77, and 78 were then compared by overlaying them onto a fourth graph, which is shown in Figure 79. The aim was to identify areas of similarity and differences in the distribution patterns between the natural airflow velocities and the two best experimental cases. This analysis revealed discernible differences, primarily for very low and high values whereas the rest of the data points were similar.

For the two best experimental cases, distribution disparities from the target natural data were primarily due to output limits for the mechanical device. The mechanical device was limited to both the low and high-speed settings which accounted for the distribution differences.

However, in light of these observations, the analysis of the data distributions suggests that the two experimental cases effectively replicate the distribution of the data from the Blacksburg weather file. While minor variations occurred at the lower and upper ends of the distributions, largely due to output limits from the mechanical device, the overall alignment between the two best experimental cases and the natural distribution was promising.

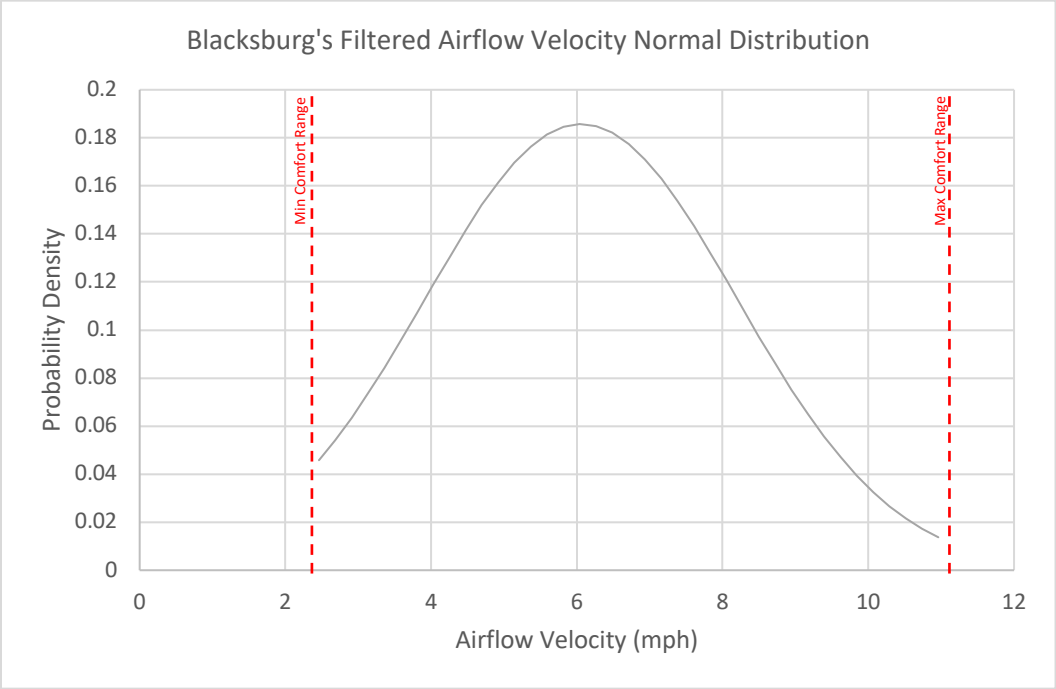

Figure 76: Filtered Airflow Velocity Normal Distribution from the Blacksburg Weather File and the Natural Comfort Airflow Speed Range.

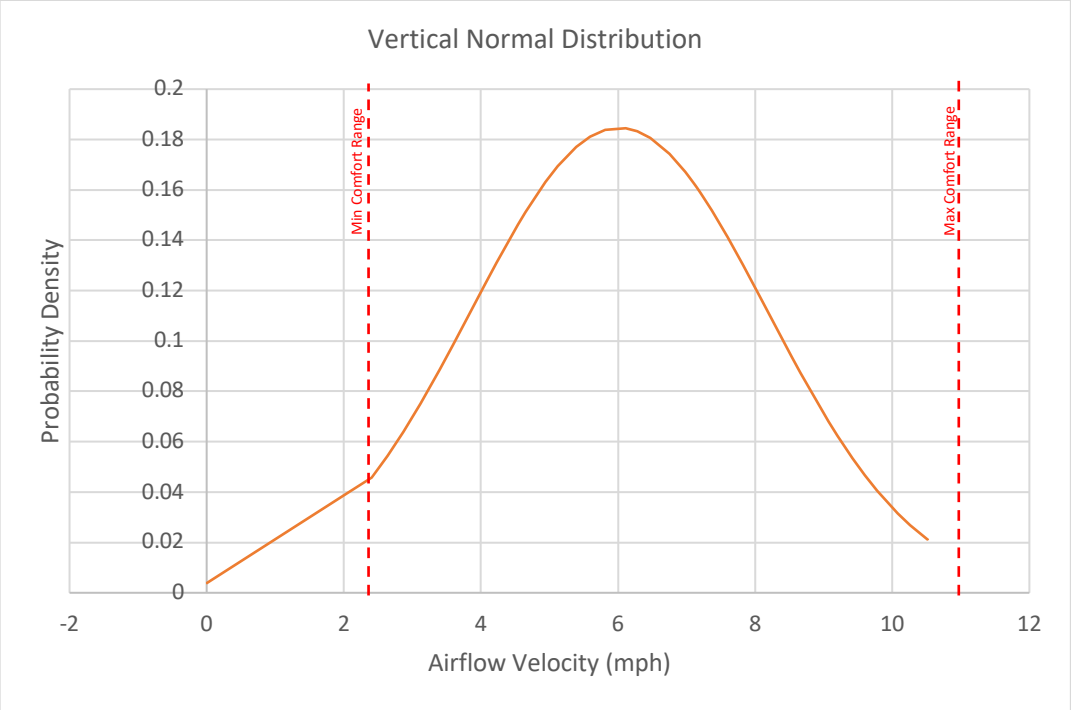

Figure 77: Vertical Normal Distribution.

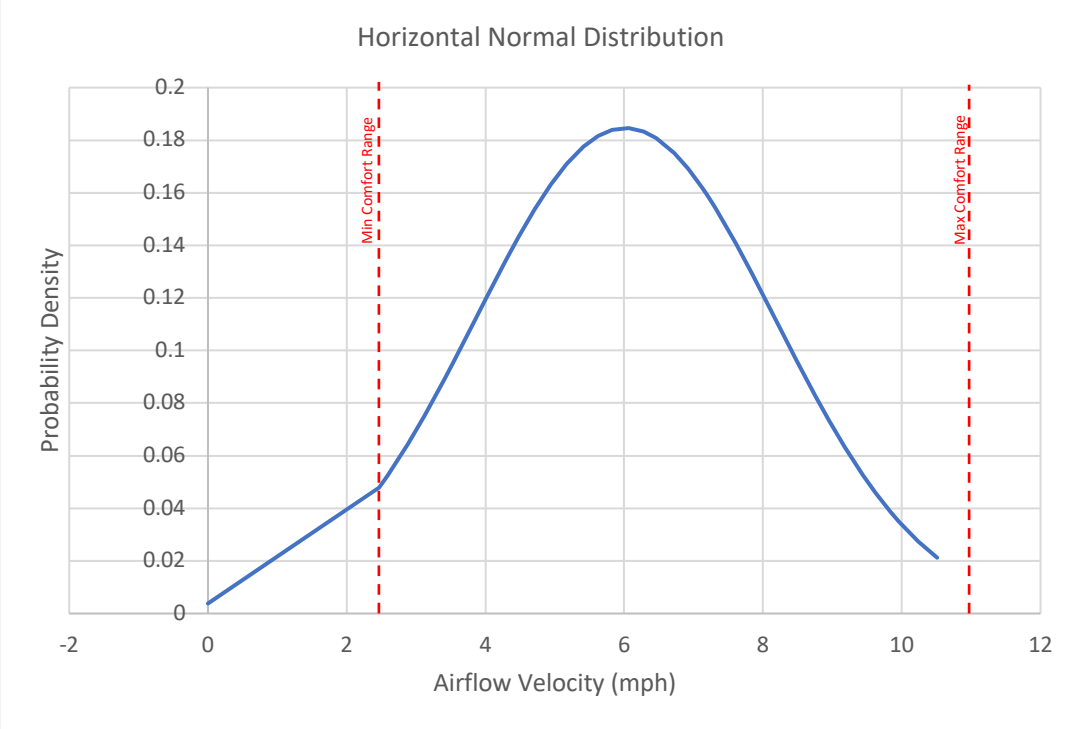

Figure 78: Horizontal Normal Distribution.

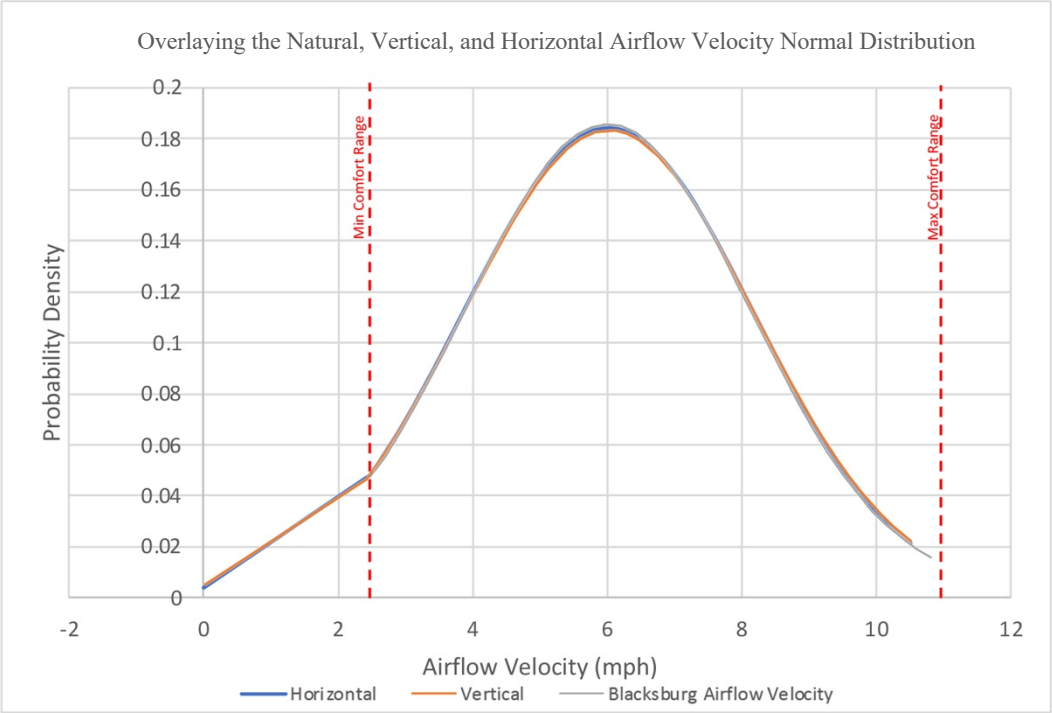

Figure 79: Overlaying the Natural, Vertical, and Horizontal Airflow Velocity Normal Distribution.

6.5. Summary

This chapter delves into the data collection process, results, and analysis. The initial focus on the diffusers revealed unexpected challenges, leading to their exclusion from the experiment due to their negative impact on airflow velocity and on the performance of the mechanical device. The chapter then details the iterative development of the prototype, emphasizing the adjustments made to variables to achieve the desired results.

The experimental variables and test cases were subsequently refined, with a focus on airflow direction (directed upward, forward, and downward) and blade angles (0, and 45). The chapter provides a detailed account of the experimental setups for different blade angles and mechanical device orientations, including vertically and horizontally oriented devices with the three determined airflow directions and the two blade angle options. For the options with directed upward and downward airflow, the mechanical device was tilted up and down, respectively, by

35-degrees to direct the airflow toward the sensor. Measurements were recorded at 10-second intervals, capturing dynamic changes in airflow velocities resulting from fan speed adjustments.

The evaluation of the experimental configurations considered factors such as natural airflow velocity range, minimum correlation coefficients, airflow velocity fluctuations, turbulence intensity, and normal distribution. The analysis identified two promising cases with 0-degree blade angles, vertically and horizontally oriented devices with direct forward airflow. These cases demonstrated a strong correlation with natural airflow patterns, effectively replicating velocity fluctuations, turbulence intensity, and normal distribution.

The Minimum Correlation Coefficient was calculated for the selected cases, revealing high values (0.939 and 0.938) indicative of a strong relationship with the target natural airflow patterns. Furthermore, the analysis of airflow velocity fluctuations showed close alignment between the selected cases and natural fluctuations, supporting the claim that these configurations effectively mimic natural airflow.

The consideration of TI highlighted the ability of the selected cases to replicate natural turbulence patterns, with minor deviations attributed to mechanical device limitations. Lastly, the analysis of normal distribution indicated that while some variations occurred at the extremes, the overall distribution of the selected cases closely resembled that of natural airflow.

In conclusion, the findings suggest that the BLNAS, specifically the vertically and horizontally oriented devices with direct forward airflow and 0-degree blade angles, holds promise in replicating natural airflow patterns. Despite some limitations related to mechanical device constraints, these configurations exhibit a strong correlation, effectively capture airflow fluctuations, TI, and mimic the normal distribution seen in natural airflow.

7.Chapter Seven: Proposed Designs and Conclusion

This chapter presents the proposed design for integrating the mechanical device within the Steelcase workstation. The chapter also presents a summary of the research, contributions to the body of knowledge, conclusion, and suggested future research.

7.1. Proposed Designs

An important step in the implementation of the BLNAS is the integration of the mechanical device within the workstation. This section presents the proposed design for this integration. The BLNAS was designed mainly to enhance occupants' health, wellness, and well-being by replicating and optimizing natural airflow patterns within indoor environments. For this, attention was paid to its appearance and integration within the workstation. On the other hand, the ready design of the Steelcase workstation’s screen was taken into consideration. Below is a description of each proposed design.

7.1.1. Vertically Oriented Mechanical Device Integration

For the vertically oriented mechanical device configuration, the following design steps were applied:

1. The Mechanical device was integrated into the workstation's partition wall, positioned directly in front of the occupant.
2. The device is located at the midpoint of the side of the workstation, ensuring optimal airflow distribution at the location of a seated occupant.
3. The device blade angle was set at 0 degrees, as with the research findings.
4. The device is placed 70 cm away from the occupant's head.
5. The vertical positioning allows for easy height adjustment to correspond with the variable height settings of the workstation, while ensuring that it remains consistently aligned with the occupant.

6. Vertical panels are used to integrate with the appearance of the workstation partition wall and to enhance the direction of the mechanical device.
7. Lighting panels are added. These lighting panels might be used as part of a biophilic light system.

Figure 80 presents the proposed design for the vertical option and Figure 81 presents the specifications of this design.

Figure 80: The Proposed Design for the Vertical Option.

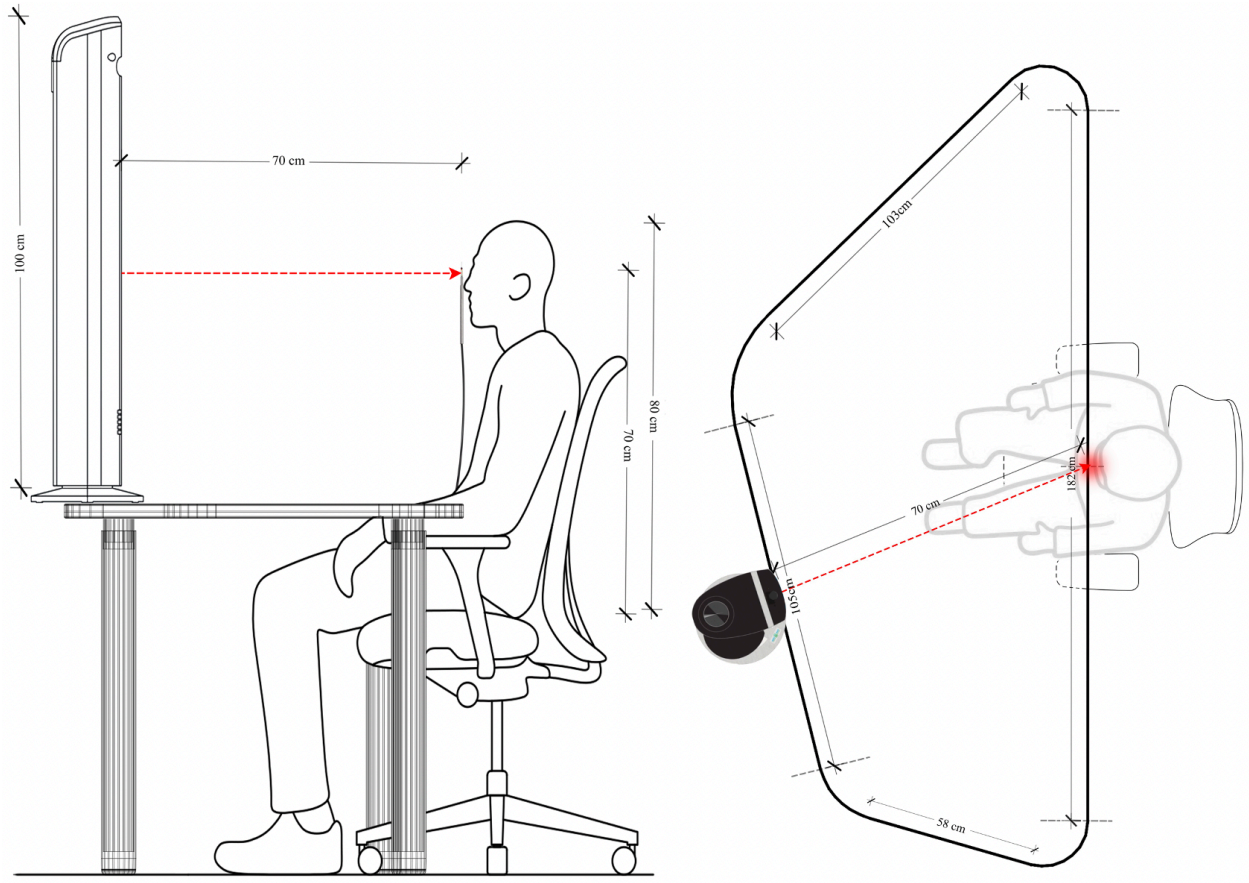

Figure 81: The Specifications of the Proposed Design for the Vertical Option.

7.1.2. Horizontally Oriented Mechanical Device Integration

For the horizontally oriented mechanical device configuration, the following design steps were applied:

1. The Mechanical device was integrated into the workstation's screen, positioned directly in front of the occupant.
2. The device is located at the midpoint of the side of the workstation, ensuring optimal airflow distribution at the location of a seated occupant.
3. Similar to the vertical configuration, the device maintained a 0-degree blade angle, adhering to the research findings.

4. It is positioned 50 cm above the level of the workstation, ensuring compatibility with the workstation's adjustable height feature, and 70 cm away from the occupant’s head.
5. The adjustable height feature enables consistent alignment with the occupant, regardless of changes in workstation height.
6. Horizontal panels are used to integrate with the appearance of the workstation partition wall and to enhance the direction of the mechanical device.
7. Lighting panels are added. These lighting panels might be used as part of a biophilic light system.

Figure 82 presents the proposed design for the horizontal option and Figure 83 presents the specifications of this design.

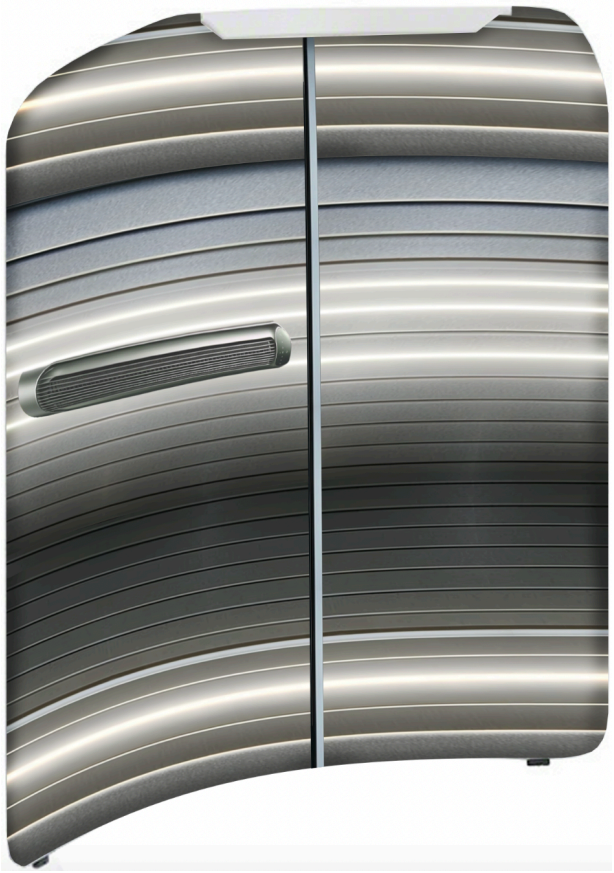

Figure 82: The Proposed Design for the Horizontal Option.

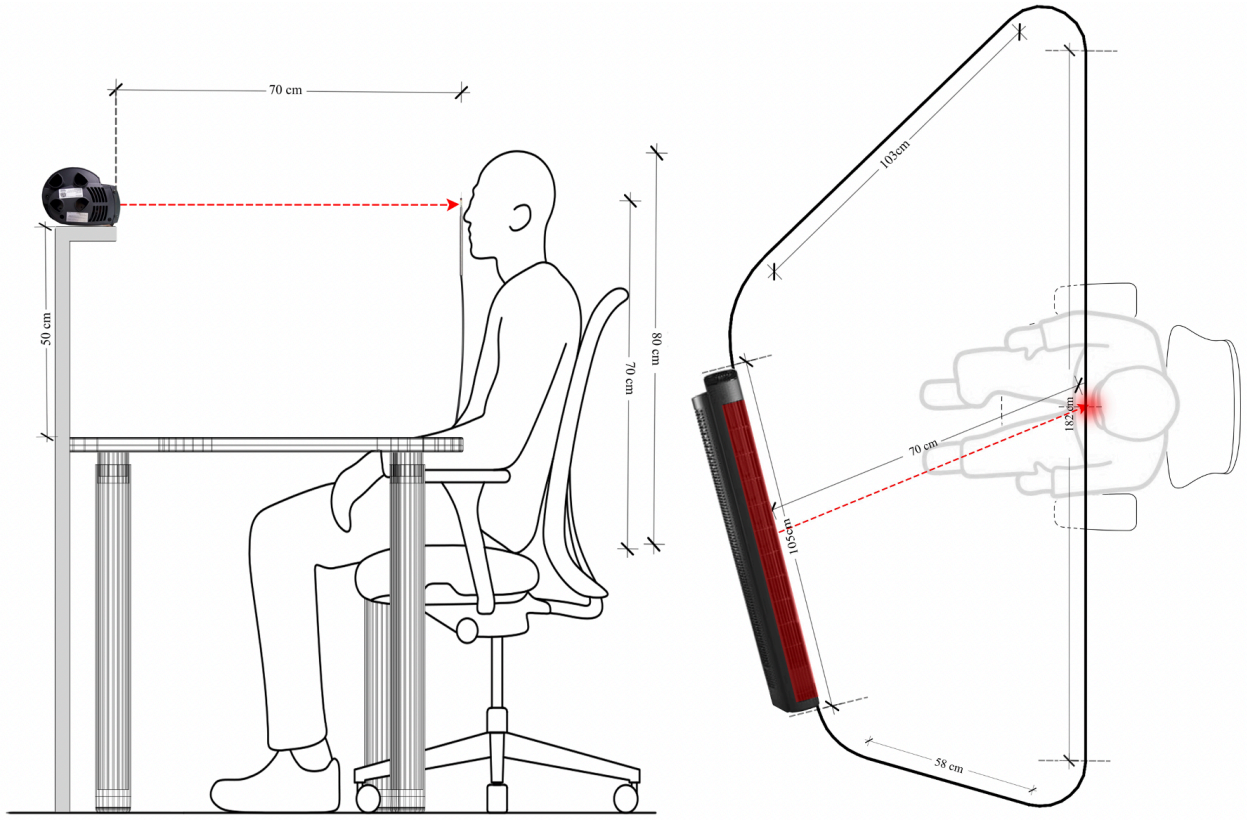

Figure 83: The Specifications of the Proposed Design for the Horizontal Option.

7.2. Conclusion

7.2.1. Introduction

While sustainability and energy efficiency are crucial aspects of modern building design, it is equally essential to create indoor environments that promote physical and psychological health, comfort, and productivity. This research has explored the critical intersection between architecture, biophilic design, and indoor environmental quality. The focus of this research has been on the need to prioritize the well-being and productivity of building occupants, considering that people in industrialized nations spend approximately 90% of their time indoors.

The COVID-19 pandemic has underscored the significance of indoor environments and their profound impact on occupants. The isolation from nature and the outside world in closed, crowded spaces can lead to various health issues, including the well-documented phenomena of

sick building syndrome. Therefore, the primary objective of this research has been to emphasize the importance of enhancing the connection between building users and nature.

Biophilic design principles have emerged as a promising solution to bridge this gap. By incorporating natural elements into the built environment and enabling occupants to engage with nature while inside a building, biophilic design can improve physical and mental well-being, reduce stress, increase productivity, and mitigate various health problems. Biophilic patterns, including elements such as natural light, materials, plants, and airflow, have been identified as key components in creating biophilic indoor environments.

Airflow, as one of these biophilic patterns, plays a crucial role in ensuring a comfortable and healthy indoor environment. While natural ventilation is a common method for enhancing airflow, alternative approaches, such as mechanical ventilation systems, heat recovery, and air filtration, can also contribute to improving indoor environmental quality. The integration of these methods with natural ventilation allows for the creation of optimal airflow conditions within biophilic designs.

Recognizing the potential of biophilic design and airflow improvement, this research has proposed the development of a dedicated system to simulate natural air movement in indoor environments. This system aims to replicate the variability of natural airflow patterns and can be integrated into modular personal workstations to enhance the biophilic work environment.

The problem statement highlights the challenges associated with integrating natural ventilation into all building types and climate zones, as well as the intermittent nature of natural ventilation. To address these challenges, the research suggests the possibility of redesigning HVAC systems to simulate natural airflow patterns. However, the complexity of this endeavor makes it more feasible to develop a localized mechanical airflow system that achieves the same goals.

In pursuit of this research objective, two fundamental questions have been posed: What are the essential attributes and properties that define natural airflow patterns? And is it possible to conceptualize, design, and develop a localized airflow system that accurately replicates these

characteristics? These questions are central to the research's goals and signify the need for innovative solutions in architectural design and indoor environmental quality improvement.

7.2.2. Methodology

The research unfolded through four main phases, with a primary focus on the development of a biophilic localized airflow system replicating natural patterns within a modular workstation setting. Below is a summary of the research methodology.

1. **Phase 1: Identification of Natural Airflow Attributes**
   - 1.1 Literature Review: The characteristics of natural airflow from existing literature and standards were extracted.
   - 1.2 Weather Data Analysis: The natural airflow features from available weather data files were identified and collected.
   - 1.3 Data Organization: The data obtained from literature and weather files were organized and structured.
   - 1.4 Statistical Analysis: The structured data were analyzed statistically to determine the fundamental attributes of natural airflow.
2. **Phase 2: Experimental Design and Setup**
   - 2.1 Airflow Mechanism Identification: The candidate airflow mechanism was determined and the configuration and control strategy for a localized mechanical airflow system was optimized.
   - 2.2 Candidate Workstation: The suitable workstation for system integration was identified.
   - 2.3 Integration Process: The airflow mechanism into modular workstations was incorporated, considering outlet design and airflow directions using industrial design principles.
   - 2.4 Experimental Design: The research variables were defined, the setup parameters were established, and the airflow velocities at the occupant's location were recorded.
3. **Phase 3: Data Analysis**
   - 3.1 Statistical Analysis: The data from phase two were analyzed to refine the experiment, enhance the prototype, and provide feedback for further development.

4. **Phase 4: Prototype Selection and Design**
   4.1 Comparative Analysis: The airflow characteristics at the occupant's location were compared and analyzed with natural airflow features from phase one. The scenarios with the highest correlation were selected as the best design.

7.2.3. Research Variables

The main research variables were categorized into three primary groups:

1. **Indigenous Dependent Variables:**
   1.1 Airflow Velocity at the Occupant's Location: Measured at the occupant's position to assess the influence of BLNAS on creating desired natural airflow patterns.
   1.2 Turbulence Intensity at the Occupant's Location: Also served as a crucial parameter in evaluating the system's impact on achieving natural airflow characteristics.
2. **Indigenous Independent Variables:**
   2.1 Distribution (Diffuser Design): Vertical, horizontal, and circular diffusers were examined for their impact on achieving natural airflow patterns. The diffusers were initially considered independent variables but were later excluded due to a negative impact on the airflow velocity and the mechanical device performance.
   2.2 Airflow Velocity: Varied to simulate natural airflow velocities, enabling correlation analysis with target natural velocities. Mainly, the research depended on the 99 settings for the mechanical device airflow velocities.
   2.3 Mechanical Device Orientation: Mainly vertical and horizontal orientations were used.
   2.4 Airflow Direction: Explored in three directions; direct, downward, and upward, by positioning the prototype accordingly. The impact on airflow velocity and turbulence intensity was assessed.
   2.5 Blade Angle: Mainly 0 and 45-blade angles were used.
3. **Exogenous Variables:**
   3.1 Mechanical Device Location: It was fixed at 70 cm from the seated occupant, regardless of its position and orientation.
   3.2 Study Location (Blacksburg, Virginia): Served as a constant to establish natural airflow reference points for the experiment.

3.3 Natural Airflow Velocities: Exogenous variable derived from Blacksburg's filtered natural airflow dataset.

3.4 Natural Airflow Turbulence Intensity: Also derived from Blacksburg's filtered natural airflow dataset, providing a benchmark for comparison.

The research focused on the mechanical device's orientation and blade angles, resulting in four distinct cases: Vertically Directed Forward Airflow, Horizontally Directed Upward Airflow, Horizontally Directed Downward Airflow, and Horizontally Directed Forward Airflow. Two blade angles (0 and 45 degrees) were explored, leading to eight evaluated cases.

7.2.4. Results

After collecting and recording the airflow measurements at the location of the seated occupant for the research 8 cases, the data were analyzed statistically. Factors such as natural airflow velocity range, minimum correlation coefficients, airflow velocity fluctuations, TI, and normal distribution were considered in the analysis. Below are the key results of this analysis.

1. Two promising cases with 0-degree blade angles, vertically and horizontally oriented devices with direct forward airflow, demonstrated strong correlations with natural airflow patterns.
2. Minimum Correlation Coefficient calculations yielded high values (0.939 and 0.938) for the two promising cases, indicating a robust relationship with the target natural airflow patterns.
3. Analysis of airflow velocity fluctuations showed close alignment between selected cases and natural fluctuations, supporting their effectiveness in mimicking natural airflow.
4. Consideration of TI highlighted the ability of selected cases to replicate natural turbulence patterns, with minor deviations attributed to mechanical device limitations.
5. Analysis of normal distribution indicated that, despite some variations at the extremes, the overall distribution of selected cases closely resembled that of natural airflow.

The findings suggest that BLNAS, specifically the vertically and horizontally oriented devices with direct forward airflow and 0-degree blade angles, holds promise in replicating natural airflow patterns. Despite some limitations related to mechanical device constraints, these

configurations exhibit a strong correlation, effectively capturing airflow fluctuations, TI, and mimicking the normal distribution seen in natural airflow. These results signify a significant step forward in the development of the BLNAS, showcasing its potential to create indoor environments with airflow patterns closely resembling those found in nature.

7.2.5. Research Contributions

The significance of this research cannot be overstated, as it addresses critical issues pertaining to the adverse effects of existing buildings on human health and well-being. Moreover, it tackles the current lack of widespread application and appropriate methodologies in biophilic design, along with the shortage of empirical studies showcasing its effectiveness. As previous research has illuminated the numerous challenges that building occupants face concerning their health and well-being, with limited natural ventilation being a prominent concern, this study seeks to make an impact by:

1. Expanding the scope of biophilic design to encompass the integration of natural air movement while surmounting the limitations associated with traditional natural ventilation methods.
2. Pioneering the design and development of a prototypical localized airflow system specifically tailored for office workstations. This innovative approach aims to create a more holistic biophilic indoor environment by simulating the variability of natural airflow patterns.
3. Conducting a comprehensive performance evaluation of the prototypical system to assess its ability to closely replicate natural airflow patterns within the occupant's seating area. This empirical investigation will provide valuable insights into the practical feasibility and effectiveness of such systems in enhancing the well-being and comfort of building occupants.

It is important to emphasize the uniqueness of this research endeavor, as it not only addresses a critical gap in the field of biophilic design but also lays the foundation for future research endeavors. This work can serve as a benchmark for subsequent studies that may further develop the proposed developed BLNAS or explore the integration of other biophilic elements. Furthermore, the potential to adapt and fine-tune this system for different climatic regions

underscores its versatility and potential for broader applications, making it a pioneering contribution to the field of building design and indoor environmental quality improvement. By providing a base for future research, this study sets the stage for continued innovation and progress in creating healthier and more sustainable indoor environments.

The developed BLNAS system offers a promising solution to the challenges associated with indoor airflow. It provides occupants with the benefits of natural airflow patterns, including improved air quality, thermal comfort, and a sense of connection to nature. This research has yielded promising results, particularly in identifying the two best-case configurations that closely mimic natural airflow patterns. These findings underscore the potential of the BLNAS to create indoor environments that align with the comfort expectations of occupants and mimic the natural outdoor airflow patterns.

In summary, this research has shed light on the critical importance of prioritizing the well-being and productivity of building occupants by enhancing their connection to nature through biophilic design and improved airflow. The proposed development of a localized mechanical airflow system represents a step forward in achieving these objectives, and the answers to the fundamental questions posed will contribute to advancing the field of architecture and building design in the pursuit of healthier, more inviting, and environmentally conscious indoor spaces. While this research aims to develop a prototypical BLNAS for modular workstations, it was driven by the overarching goal of enhancing occupants' health, wellness, and well-being by replicating and optimizing natural airflow patterns within indoor environments.

7.3. Future Research

In considering the direction of airflow in the development of the BLNAS for modular workstations, the researcher acknowledges the potential discomfort associated with directing airflow toward a person's face, as well as the natural airflow experienced on other parts of the body such as the arms or legs, contingent upon clothing and environmental factors. However, it is crucial to recognize that the forehead houses a significant concentration of primary thermal sensors in the human body.

Understanding this, the decision to direct airflow towards the head stems from the necessity to measure its impact on the densest region of thermal sensors. While this approach may pose discomfort concerns, particularly for some individuals, it allows for a more targeted assessment of the physiological responses to localized airflow.

In light of this understanding, future research might address these concerns and enhance user comfort. One approach could involve providing users with the flexibility to customize the location of the BLNAS according to their preferred body parts, thereby accommodating individual preferences and minimizing discomfort. Additionally, future research endeavors could explore expanding the area of distributed airflow to cover a broader section of the human body, thereby promoting a more comprehensive and inclusive approach to biophilic airflow simulation.

By acknowledging the potential discomfort associated with directing airflow towards the face while emphasizing the importance of targeting the forehead area for thermal sensor measurement, this research lays the groundwork for future investigations aimed at optimizing the effectiveness and user experience of localized airflow systems within modular workstations.

On the other hand, future research endeavors might focus on the practical implementation of the BLNAS, including its manufacturing and real-world testing on occupants. This iterative approach will ensure that the system is refined and optimized for broader applications, and test its impact on the occupants' health, wellness, and well-being.

As mentioned before, the researcher recognizes that there will be a need for at least two additional phases that will be beyond the scope of the present work. In phase five, the interaction of the prototypical system with the mechanical system and its' forced air distribution will need to be determined. In Phase six, which is also beyond the scope of the current study, the performance of the prototype needs to be assessed.

Based on this, two critical questions will be suggested for future research as follows:

1. What is the impact of the traditional mechanical system on the developed prototypical system?
2. What is the impact of the prototypical system on occupants' physiological and psychological aspects?

To examine these proposed questions, both qualitative and quantitative techniques are necessary for answering such questions. Qualitative techniques involve gathering information through interviews or focus groups in order to identify key features that should be included in the product design. On the other hand, quantitative techniques involve using statistical methods, computer simulations, and questionnaire to measure environmental performance, energy efficiency, cost-effectiveness, etc.

Table 27 presents the proposed research questions, the methodological steps that will cover them, the methods that will be used to investigate them, and their expected results.

Table 27: The Proposed Research Questions and Answering Procedure.

Research Question	Research Step	Method of Investigation	Expected Result
1. What is the impact of the traditional mechanical system on the developed prototypical system?	Phase 5 Step 1	Computational Fluid Dynamics (CFD)	Determine the optimum air distribution of a mechanical forced airflow mechanism (prototype).
	Phase 5 Step 2	Statistical Analysis	Determine the correlation between the resulting airflow pattern to the desired "natural" airflow characteristics as determined in phase 1.
2. What is the impact of the prototypical system on occupants' physiological and psychological aspects?	Phase 6 Step 1	Real Experiment	Test the occupants' responses in the indoor environment while using the prototype and without using it.
	Phase 6 Step 2	Questionnaire Bio-monitoring Sensors Statistical Analysis	Determine the impact of the prototype on occupants' physiological and psychological aspects.

Based on the main research goal, objectives, and structure, a detailed presentation of the full research procedure and methodology was illustrated in Figure 84 and Figure 85. Figure 84 presents the full structure and procedure for current and future research while Figure 85 is a detailed presentation of the current and future research methodology. Figures 84 and 85 present

the full six phases. It's important to mention that the first four phases were related to this research while the two other phases are related to the proposed future questions. All phases were mentioned, designed, and connected in Figures 84 and 85 to present the larger image of the research and focus on the larger research gap that the suggested research aims to highlight and cover.

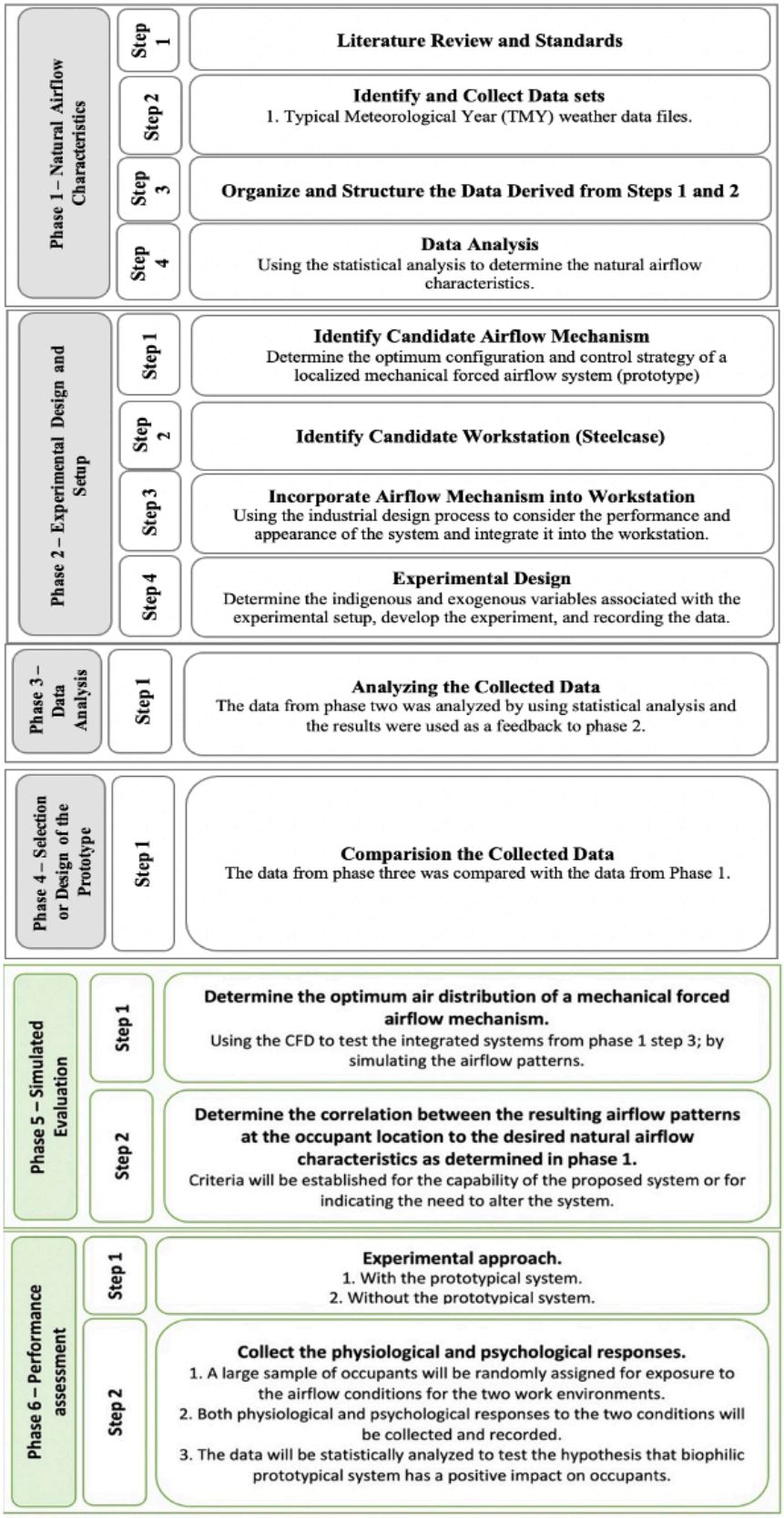

Figure 84: Current and Future Research Structure and Procedure.

Based on this, Figure 85 shows a detailed presentation of the current and future research methodology. Phases 1 to 4 were related to the current research where the characteristics of natural airflow were determined, a real experiment was designed, the collected data was analyzed, and the best prototypes that mimic natural airflow features were chosen. The resulting data will be used to answer the two other suggested questions which are; What is the impact of the traditional mechanical system on the developed prototypical system? and What is the impact of the prototypical system on occupants' physiological and psychological aspects? Phase 5, simulated evaluation, was designed to answer the first question and evaluate the impact of the traditional HVAC system on the prototypical system. Phase 6, performance assessment, was designed to answer the second question and evaluate the impact of the prototypical system on occupants' physiological and psychological aspects.

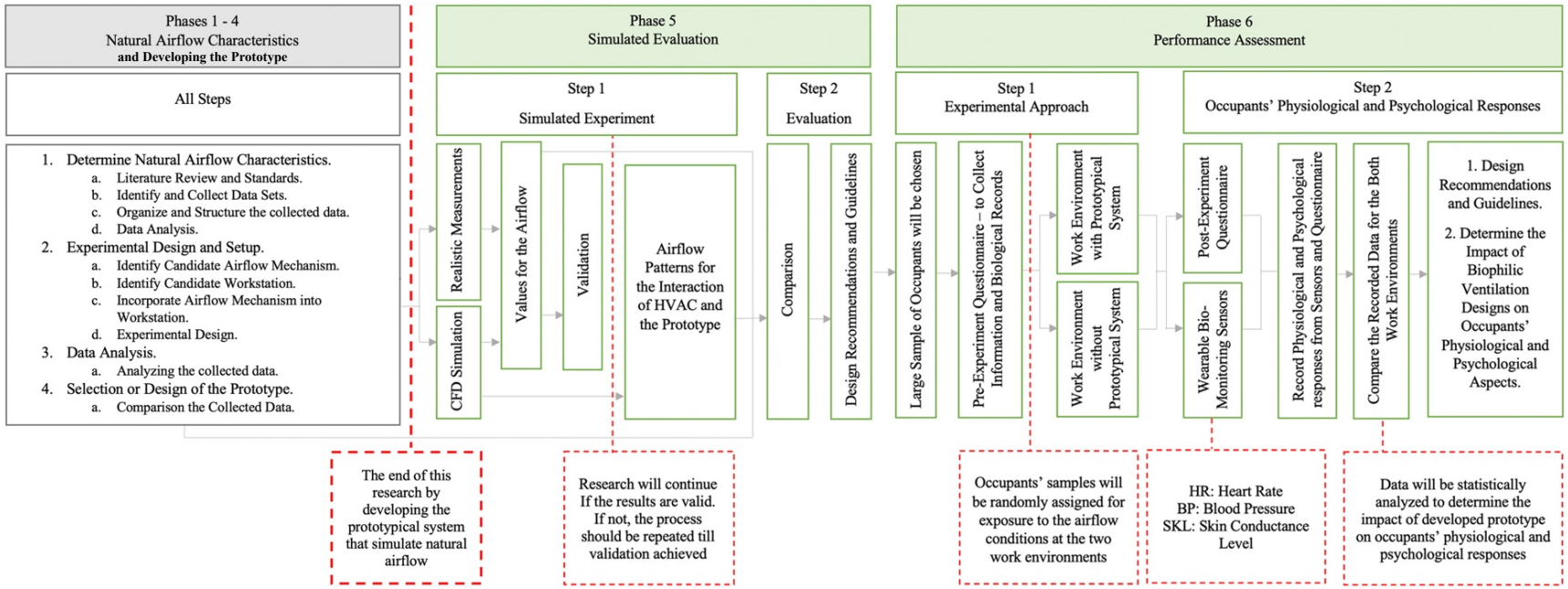

Figure 85: Detailed Presentation for the Current and Future Research Methodology.

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9.Appendixes

9.1 Appendix A: The Full Filtered Hourly Weather Data Sets for Blacksburg, VA and Los Angeles, CA

Table 28: The Full Filtered Hourly Weather Data Sets for Blacksburg, VA and Los Angeles, CA.

	Blacksburg, VA		Los Angeles, CA	
	Air Temperature (F)	Airflow Velocity (mph)	Air Temperature (F)	Airflow Velocity (mph)
1	68	10.289887	69.08	5.816023
2	68	9.171421	69.08	9.171421
3	70.880005	9.171421	69.08	9.171421
4	68	8.052955	69.98	8.052955
5	71.96	10.289887	71.06	5.816023
6	71.96	6.7107964	69.08	8.052955
7	69.98	8.052955	71.06	9.171421
8	68	6.7107964	75.02	4.697557
9	74.84	10.289887	69.08	10.289887
10	75.92	6.7107964	69.98	8.052955
11	77.9	9.171421	68	4.697557
12	77.9	9.171421	73.94	5.816023
13	73.94	10.289887	69.98	5.816023
14	68.9	6.7107964	73.94	8.052955
15	68.9	5.59233	71.96	9.171421
16	72.86	8.052955	69.08	6.9344893
17	72.86	10.289887	73.04	9.171421
18	69.98	8.052955	75.02	8.052955
19	68	4.473864	78.08	9.171421
20	68	3.3553982	78.98	8.052955
21	69.98	5.59233	80.06	9.171421
22	69.98	6.7107964	75.02	9.171421
23	71.96	10.289887	71.06	9.171421
24	72.86	9.171421	68	8.052955
25	71.96	10.289887	75.02	10.289887
26	69.98	8.052955	75.92	9.171421
27	68	9.171421	82.04	6.9344893

28	79.880005	10.289887	82.04	10.289887
29	72.86	3.3553982	80.06	8.052955
30	73.94	8.052955	69.08	5.816023
31	68	5.59233	69.98	10.289887
32	70.880005	3.3553982	69.08	9.171421
33	71.96	4.473864	68	8.052955
34	68	5.59233	69.08	6.9344893
35	68	5.59233	78.08	3.3553982
36	70.880005	10.289887	73.94	9.171421
37	68	8.052955	71.06	6.9344893
38	70.880005	10.289887	73.94	3.3553982
39	69.98	9.171421	69.08	5.816023
40	69.98	5.59233	69.98	9.171421
41	68.9	5.59233	71.06	8.052955
42	68	4.473864	75.92	4.697557
43	68	4.473864	73.04	10.289887
44	73.4	4.697557	69.98	8.052955
45	74.66	4.697557	71.96	9.171421
46	75.2	4.697557	69.98	10.289887
47	73.4	9.171421	71.96	8.052955
48	71.6	9.171421	71.96	9.171421
49	69.8	8.052955	71.96	6.9344893
50	68	5.816023	68	8.052955
51	71.6	6.9344893	71.96	5.816023
52	68	3.3553982	78.08	4.697557
53	71.6	3.3553982	80.06	4.697557
54	73.4	8.052955	82.94	6.9344893
55	73.4	8.052955	78.98	9.171421
56	73.4	3.3553982	71.06	8.052955
57	69.8	6.9344893	68	6.9344893
58	73.4	9.171421	71.96	6.9344893
59	71.6	10.289887	75.92	6.9344893
60	69.8	8.052955	80.06	4.697557
61	71.6	4.697557	69.98	9.171421
62	71.6	6.9344893	68	8.052955
63	68	3.3553982	69.08	3.3553982
64	71.6	6.9344893	69.98	4.697557
65	75.2	9.171421	73.94	4.697557
66	75.2	6.9344893	71.06	6.9344893
67	78.8	9.171421	78.08	10.289887
68	75.2	10.289887	80.96	5.816023

69	77	9.171421	80.96	5.816023
70	69.8	3.3553982	75.92	6.9344893
71	69.8	5.816023	75.92	6.9344893
72	69.8	4.697557	75.02	9.171421
73	69.8	5.816023	68	5.816023
74	68	5.816023	69.98	6.9344893
75	69.8	3.3553982	69.08	8.052955
76	73.4	5.816023	71.96	3.3553982
77	78.8	5.816023	71.96	8.052955
78	75.2	8.052955	68	10.289887
79	77	6.9344893	71.96	9.171421
80	78.8	8.052955	69.98	8.052955
81	75.2	9.171421	73.04	5.816023
82	69.8	5.816023	71.96	8.052955
83	68	8.052955	73.94	8.052955
84	68	4.697557	78.08	5.816023
85	69.8	3.3553982	68	9.171421
86	78.8	8.052955	71.96	9.171421
87	80.6	9.171421	77	5.816023
88	82.76	10.960967	78.08	4.697557
89	68	8.052955	69.08	4.697557
90	68	10.289887	68	5.816023
91	68.36	8.052955	73.04	5.816023
92	68	5.816023	75.92	4.697557
93	71.6	8.052955	80.06	6.9344893
94	71.6	9.171421	69.98	10.289887
95	68	7.6055694	69.08	10.289887
96	69.8	4.697557	71.96	4.697557
97	74.48	5.368637	71.06	5.816023
98	78.8	5.816023	69.98	8.052955
99	80.6	9.171421	69.08	10.289887
100	80.6	9.171421	73.04	8.052955
101	77	5.816023	71.96	6.9344893
102	75.2	6.9344893	75.92	6.9344893
103	73.4	8.052955	73.94	6.9344893
104	71.6	9.171421	71.96	9.171421
105	69.8	9.171421	71.96	9.171421
106	71.24	5.368637	69.08	5.816023
107	75.2	8.052955	69.98	5.816023
108	73.4	9.171421	73.94	9.171421
109	71.6	8.052955	73.04	8.052955

110	71.6	10.289887	75.92	8.052955
111	71.6	8.052955	78.98	9.171421
112	69.8	5.816023	80.96	10.289887
113	69.8	5.816023	68	5.816023
114	69.8	6.9344893	68	6.9344893
115	71.6	6.9344893	69.08	10.289887
116	68	3.3553982	69.08	9.171421
117	69.8	6.9344893	69.08	10.289887
118	68	6.9344893	71.06	10.289887
119	69.8	6.9344893	69.08	8.052955
120	73.4	8.052955	69.08	6.9344893
121	75.2	6.9344893	69.08	9.171421
122	75.2	10.289887	69.08	10.289887
123	75.2	8.052955	68	3.3553982
124	75.2	6.9344893	69.08	8.052955
125	73.4	8.052955	69.08	10.289887
126	70.34	6.487103	69.98	5.816023
127	71.6	3.3553982	69.08	9.171421
128	73.4	6.9344893	69.08	8.052955
129	78.8	8.052955	69.98	8.052955
130	77	5.816023	71.06	9.171421
131	75.2	5.816023	68	3.3553982
132	71.6	3.3553982	69.08	10.289887
133	69.8	3.3553982	68	10.289887
134	69.8	6.9344893	68	5.816023
135	69.8	8.052955	69.08	9.171421
136	69.8	8.052955	69.08	6.9344893
137	68	4.697557	69.98	5.816023
138	69.8	4.697557	68	10.289887
139	73.4	3.3553982	68	9.171421
140	73.4	5.816023	69.08	9.171421
141	75.2	4.697557	68	8.052955
142	75.2	4.697557	68	3.3553982
143	68	9.171421	73.04	4.697557
144	73.4	6.9344893	68	3.3553982
145	75.2	8.052955	71.96	6.9344893
146	78.8	9.171421	75.92	5.816023
147	78.8	6.9344893	82.94	9.171421
148	80.6	8.052955	71.96	10.289887
149	80.6	8.052955	71.96	10.289887
150	82.4	8.052955	69.98	5.816023

151	77	4.697557	69.08	8.052955
152	72.14	4.0264773	73.94	10.289887
153	71.6	3.3553982	78.08	10.289887
154	80.6	4.697557	82.94	4.697557
155	82.4	8.052955	80.96	9.171421
156	80.6	6.9344893	71.96	10.289887
157	77	5.816023	71.06	6.9344893
158	73.4	3.3553982	69.08	4.697557
159	72.86	3.5790913	73.94	6.9344893
160	77	6.9344893	80.06	4.697557
161	78.8	6.9344893	71.06	9.171421
162	80.6	4.697557	71.06	8.052955
163	82.4	6.9344893	69.08	4.697557
164	80.6	6.9344893	68	5.816023
165	82.4	3.3553982	71.06	5.816023
166	77	5.816023	69.98	10.289887
167	75.2	8.052955	71.06	10.289887
168	69.8	6.9344893	69.08	8.052955
169	75.2	8.052955	69.08	10.289887
170	69.8	5.816023	68	9.171421
171	71.6	4.697557	69.08	10.289887
172	78.8	3.3553982	69.08	9.171421
173	80.6	3.3553982	68	8.052955
174	80.06	5.816023	68	9.171421
175	78.8	8.052955	68	10.289887
176	78.8	9.171421	68	10.289887
177	77	10.289887	68	8.052955
178	75.2	5.816023	69.98	8.052955
179	71.6	4.697557	71.06	10.289887
180	70.16	4.0264773	71.06	9.171421
181	73.4	4.697557	69.08	9.171421
182	75.2	8.052955	69.08	6.9344893
183	75.2	9.171421	69.08	5.816023
184	76.46	8.052955	69.98	8.052955
185	77	6.9344893	69.98	9.171421
186	77	10.289887	71.06	10.289887
187	77	10.289887	69.08	9.171421
188	75.2	6.9344893	69.08	3.3553982
189	73.04	6.9344893	71.06	6.9344893
190	69.8	6.9344893	68	9.171421
191	71.6	4.697557	69.08	9.171421

192	73.4	4.697557	69.98	9.171421
193	75.2	3.3553982	68	10.289887
194	77	6.9344893	69.98	9.171421
195	77.72	6.9344893	68	9.171421
196	78.8	6.9344893	71.96	4.697557
197	80.6	9.171421	69.98	9.171421
198	78.8	8.052955	69.98	8.052955
199	78.26	8.724035	69.98	8.052955
200	77	9.171421	71.06	9.171421
201	75.2	6.9344893	71.06	8.052955
202	73.94	3.5790913	71.06	9.171421
203	69.8	6.9344893	68	10.289887
204	74.119995	6.9344893	71.96	3.3553982
205	78.8	6.9344893	68	8.052955
206	80.6	8.052955	68	10.289887
207	82.4	6.9344893	69.98	9.171421
208	82.4	8.052955	68	9.171421
209	70.880005	5.59233	69.08	6.9344893
210	71.96	4.473864	69.98	10.289887
211	71.96	5.59233	68	9.171421
212	71.96	4.473864	69.08	4.697557
213	73.94	8.052955	68	9.171421
214	72.86	8.052955	69.08	9.171421
215	71.96	8.052955	71.06	4.697557
216	70.880005	6.7107964	75.92	3.3553982
217	68.9	5.59233	75.02	10.289887
218	69.98	8.052955	75.02	10.289887
219	69.98	4.473864	71.96	10.289887
220	72.86	8.052955	71.06	9.171421
221	70.880005	9.171421	69.98	5.816023
222	70.880005	5.59233	68	6.9344893
223	72.86	9.171421	73.04	4.697557
224	71.96	6.7107964	73.94	9.171421
225	68	6.7107964	73.94	10.289887
226	68	5.59233	73.94	10.289887
227	68	4.473864	68	8.052955
228	71.96	5.59233	75.02	6.9344893
229	71.96	5.59233	75.92	9.171421
230	69.98	3.3553982	77	8.052955
231	68	4.473864	73.04	10.289887
232	68.9	8.052955	71.06	10.289887

233	73.94	9.171421	69.08	5.816023
234	68	4.473864	71.96	8.052955
235	69.98	8.052955	71.06	10.289887
236	73.94	6.7107964	68	10.289887
237	74.84	3.3553982	68	9.171421
238	73.94	3.3553982	68	9.171421
239	77	3.3553982	68	6.9344893
240	80.96	5.59233	68	8.052955
241	78.98	3.3553982	68	9.171421
242	79.880005	4.473864	69.98	9.171421
243	77.54	4.473864	73.04	9.171421
244	74.84	4.473864	69.08	5.816023
245	70.880005	4.473864	69.98	6.9344893
246	68.9	4.473864	69.98	9.171421
247	68	3.3553982	71.06	9.171421
248	72.86	4.473864	75.02	3.3553982
249	75.92	5.59233	78.98	9.171421
250	77.9	3.3553982	73.94	10.289887
251	80.96	4.473864	68	9.171421
252	80.96	5.59233	68	4.697557
253	68	3.3553982	75.92	3.3553982
254	68	3.3553982	75.92	8.052955
255	69.98	6.7107964	78.08	8.052955
256	72.86	8.052955	77	9.171421
257	71.96	6.7107964	75.92	9.171421
258	77.9	8.052955	71.96	9.171421
259	75.92	8.052955	68	10.289887
260	77.9	10.289887	75.02	3.3553982
261	77.9	9.171421	78.08	6.9344893
262	77	8.052955	78.08	10.289887
263	77.9	9.171421	78.08	10.289887
264	70.880005	8.052955	68	10.289887
265	70.880005	8.052955	68	6.9344893
266	68.9	9.171421	71.06	3.3553982
267	68.9	10.289887	73.94	8.052955
268	69.8	9.171421	75.02	8.052955
269	69.44	8.052955	75.92	10.289887
270	68.72	6.7107964	69.98	9.171421
271	70.880005	5.59233	69.98	9.171421
272	71.96	4.473864	69.98	9.171421
273	72.86	4.473864	71.96	9.171421

274	72.86	5.59233	71.96	9.171421
275	69.98	6.7107964	71.06	6.9344893
276	72.86	3.3553982	68	10.289887
277	75.92	9.171421	68	5.816023
278	74.84	6.7107964	69.98	10.289887
279	74.84	4.473864	68	10.289887
280	70.880005	4.473864	69.08	4.697557
281	69.98	6.7107964	68	4.697557
282	72.86	4.473864	71.06	9.171421
283	70.880005	4.473864	71.06	10.289887
284	69.98	6.7107964	69.98	5.816023
285	69.98	6.7107964	69.98	10.289887
286	73.94	8.052955	69.08	10.289887
287	74.84	9.171421	69.08	10.289887
288	74.84	6.7107964	69.08	10.289887
289	72.86	8.052955	71.96	3.3553982
290	69.98	5.59233	75.92	6.9344893
291	69.98	6.7107964	75.92	10.289887
292	72.86	6.7107964	75.92	10.289887
293	74.84	8.052955	69.98	9.171421
294	73.94	6.7107964	69.98	5.816023
295	72.86	9.171421	71.96	9.171421
296	77	10.289887	71.06	8.052955
297	78.98	8.052955	71.96	9.171421
298	77.9	10.289887	69.08	8.052955
299	77	6.7107964	69.08	5.816023
300	72.86	4.473864	71.06	6.9344893
301	69.98	4.473864	73.04	10.289887
302	74.84	4.473864	73.94	8.052955
303	77.9	4.473864	73.94	8.052955
304	78.98	5.59233	68	6.9344893
305	81.86	5.59233	69.08	5.816023
306	82.94	6.7107964	71.06	5.816023
307	81.86	5.59233	75.02	6.9344893
308	79.880005	4.473864	77	8.052955
309	77	3.3553982	77	10.289887
310	70.880005	3.3553982	68	6.9344893
311	69.98	5.59233	69.98	10.289887
312	79.880005	3.3553982	68	9.171421
313	80.96	3.3553982	68	5.816023
314	74.84	8.052955	71.06	5.816023

315	74.84	3.3553982	73.04	9.171421
316	78.98	4.473864	69.98	10.289887
317	77.9	10.289887	68	9.171421
318	77.9	9.171421	68	8.052955
319	79.880005	6.7107964	68	10.289887
320	78.98	4.473864	69.08	10.289887
321	81.86	4.473864	68	10.289887
322	77.9	4.473864	68	9.171421
323	78.98	3.3553982	68	9.171421
324	68.9	3.3553982	68	6.9344893
325	79.880005	3.3553982	68	5.816023
326	82.94	9.171421	68	5.816023
327	80.96	5.59233	68	8.052955
328	79.880005	5.59233	68	6.9344893
329	70.880005	3.3553982	69.08	6.9344893
330	73.94	3.3553982	69.08	6.9344893
331	78.98	3.3553982	69.08	6.9344893
332	80.96	4.473864	69.98	4.697557
333	82.94	5.59233	71.06	6.9344893
334	81.86	10.289887	71.96	9.171421
335	78.98	4.473864	71.96	6.9344893
336	80.96	3.3553982	71.96	8.052955
337	79.880005	3.3553982	71.96	9.171421
338	77.9	5.59233	71.96	8.052955
339	73.94	4.473864	71.06	6.9344893
340	68	3.3553982	71.06	8.052955
341	68	3.3553982	71.06	4.697557
342	70.880005	4.473864	71.06	8.052955
343	71.96	3.3553982	69.98	6.9344893
344	74.84	9.171421	69.08	5.816023
345	77	8.052955	69.08	3.3553982
346	81.86	3.3553982	69.08	5.816023
347	70.880005	5.59233	71.06	4.697557
348	68.9	4.473864	80.06	4.697557
349	71.96	5.59233	77	10.289887
350	77	8.052955	69.98	10.289887
351	72.86	4.473864	69.08	10.289887
352	78.98	8.052955	68	9.171421
353	75.92	10.289887	68	6.9344893
354	75.92	5.59233	68	9.171421
355	77	8.052955	69.08	9.171421

356	77.9	5.59233	69.98	9.171421
357	74.84	3.3553982	73.04	5.816023
358	68.9	4.473864	73.04	10.289887
359	72.14	6.2634096	68	10.289887
360	74.84	8.052955	68	4.697557
361	75.92	9.171421	68	5.816023
362	77.9	6.7107964	71.06	8.052955
363	79.880005	8.052955	73.04	10.289887
364	81.86	10.289887	71.96	10.289887
365	81.86	6.7107964	69.08	4.697557
366	81.86	9.171421	71.96	3.3553982
367	79.880005	9.171421	77	4.697557
368	82.94	9.171421	75.02	9.171421
369	82.94	5.59233	71.06	3.3553982
370	78.98	9.171421	73.04	5.816023
371	77	5.59233	75.92	9.171421
372	70.880005	4.473864	73.04	10.289887
373	70.880005	5.59233	68	10.289887
374	74.84	5.59233	68	5.816023
375	77.9	9.171421	71.96	10.289887
376	79.880005	10.289887	71.96	10.289887
377	81.86	6.7107964	71.96	10.289887
378	77.9	4.473864	71.06	8.052955
379	75.92	5.59233	69.98	4.697557
380	77.9	8.052955	71.96	6.9344893
381	75.92	6.7107964	75.02	9.171421
382	74.84	3.3553982	75.92	10.289887
383	72.86	3.3553982	78.08	9.171421
384	75.92	8.052955	75.02	10.289887
385	74.84	9.171421	73.94	10.289887
386	74.84	10.289887	71.96	9.171421
387	70.880005	9.171421	71.06	3.3553982
388	69.98	10.289887	69.98	4.697557
389	70.880005	8.052955	69.98	5.816023
390	71.96	9.171421	69.98	5.816023
391	71.96	8.052955	69.98	6.9344893
392	79.880005	10.289887	69.98	6.9344893
393	80.96	9.171421	69.98	6.9344893
394	82.94	5.59233	69.98	5.816023
395	82.94	5.59233	69.08	8.052955
396	79.880005	3.3553982	69.08	9.171421

397	73.94	3.3553982	69.98	8.052955
398	81.86	4.473864	75.92	6.9344893
399	77	4.473864	80.06	5.816023
400	80.96	6.7107964	80.06	9.171421
401	75.92	10.289887	82.04	9.171421
402	75.92	8.052955	69.98	10.289887
403	77	9.171421	68	9.171421
404	73.94	8.052955	68	3.3553982
405	69.98	6.7107964	69.08	5.816023
406	68	4.473864	69.08	6.9344893
407	68.9	3.3553982	69.08	5.816023
408	69.98	6.7107964	69.08	5.816023
409	71.96	9.171421	69.08	6.9344893
410	71.96	10.289887	69.08	4.697557
411	75.92	8.052955	68	5.816023
412	73.94	10.289887	68	5.816023
413	68.9	4.473864	71.06	5.816023
414	70.880005	6.7107964	77	3.3553982
415	70.880005	6.7107964	80.96	9.171421
416	73.94	3.3553982	78.08	10.289887
417	74.84	3.3553982	78.98	10.289887
418	75.92	10.289887	69.08	10.289887
419	73.94	4.473864	69.08	8.052955
420	75.92	6.7107964	69.98	10.289887
421	73.94	5.59233	69.98	10.289887
422	71.96	3.3553982	69.98	10.289887
423	70.880005	3.3553982	69.98	5.816023
424	72.86	3.3553982	73.04	3.3553982
425	74.84	4.473864	75.92	6.9344893
426	77	4.473864	71.96	9.171421
427	78.98	3.3553982	68	8.052955
428	77.9	4.473864	68	4.697557
429	78.98	3.3553982	69.98	4.697557
430	73.94	4.473864	75.02	4.697557
431	68.9	3.3553982	78.08	4.697557
432	73.94	4.473864	75.02	10.289887
433	77	4.473864	73.04	10.289887
434	81.86	4.473864	71.06	9.171421
435	82.94	4.473864	69.98	8.052955
436	82.94	4.473864	69.08	9.171421
437	78.98	3.3553982	69.08	5.816023

438	77.9	3.3553982	69.08	5.816023
439	75.92	3.3553982	69.08	3.3553982
440	81.86	4.473864	69.08	5.816023
441	80.96	5.59233	68	6.9344893
442	78.98	4.473864	68	8.052955
443	77	3.3553982	68	6.9344893
444	69.98	3.3553982	68	5.816023
445	69.98	4.473864	68	3.3553982
446	72.86	6.7107964	69.98	5.816023
447	73.94	9.171421	73.94	4.697557
448	82.94	7.6055694	75.02	10.289887
449	79.34	5.1449437	75.02	10.289887
450	71.6	4.697557	68	9.171421
451	71.6	8.052955	68	8.052955
452	69.98	9.171421	68	3.3553982
453	68	4.697557	69.98	6.9344893
454	69.44	6.9344893	73.04	3.3553982
455	71.6	5.816023	69.98	3.3553982
456	74.119995	6.9344893	73.04	6.9344893
457	77	3.3553982	77	5.816023
458	80.6	8.052955	75.92	10.289887
459	80.6	10.289887	73.94	10.289887
460	80.6	9.171421	69.98	9.171421
461	80.6	6.9344893	69.08	8.052955
462	78.8	5.816023	69.08	8.052955
463	74.119995	2.9080114	69.08	5.816023
464	77	6.9344893	69.08	3.3553982
465	80.6	5.816023	69.08	4.697557
466	82.4	4.697557	69.08	4.697557
467	81.32	4.697557	69.08	3.3553982
468	80.6	4.697557	69.08	5.816023
469	82.4	9.171421	69.08	5.816023
470	81.32	2.9080114	68	8.052955
471	77	5.816023	68	6.9344893
472	80.6	6.9344893	71.06	5.816023
473	82.4	6.9344893	73.04	5.816023
474	78.8	3.3553982	75.02	6.9344893
475	80.6	6.9344893	78.08	9.171421
476	75.92	2.4606254	71.06	9.171421
477	73.4	4.697557	69.98	8.052955
478	71.6	4.697557	69.98	8.052955

479	75.2	6.9344893	69.98	5.816023
480	80.6	6.9344893	69.08	5.816023
481	82.4	6.9344893	69.08	6.9344893
482	82.4	4.697557	69.08	5.816023
483	82.4	9.171421	69.08	5.816023
484	78.8	4.697557	69.08	6.9344893
485	73.4	6.9344893	69.08	8.052955
486	69.8	3.3553982	69.08	6.9344893
487	68	4.697557	69.08	6.9344893
488	68	3.3553982	69.98	6.9344893
489	68	3.3553982	73.04	6.9344893
490	68	3.3553982	75.02	9.171421
491	68	3.3553982	75.92	10.289887
492	69.8	3.3553982	68	9.171421
493	73.4	3.3553982	68	8.052955
494	75.2	6.9344893	69.08	8.052955
495	78.8	8.052955	69.08	10.289887
496	80.6	4.697557	68	6.9344893
497	82.4	9.171421	69.98	6.9344893
498	79.52	4.697557	71.96	8.052955
499	75.2	3.3553982	69.98	10.289887
500	71.6	3.3553982	71.96	9.171421
501	73.4	8.052955	69.98	9.171421
502	80.6	5.816023	69.98	9.171421
503	80.6	9.171421	71.06	10.289887
504	82.4	6.9344893	68	8.052955
505	80.6	3.3553982	69.98	8.052955
506	78.8	3.3553982	69.98	8.052955
507	75.2	4.697557	71.06	10.289887
508	75.2	3.3553982	71.96	10.289887
509	71.6	3.3553982	68	8.052955
510	80.6	6.9344893	68	3.3553982
511	82.4	10.289887	71.06	6.9344893
512	82.4	8.052955	71.96	9.171421
513	69.8	3.3553982	68	4.697557
514	71.6	6.9344893	71.96	3.3553982
515	71.6	6.9344893	75.02	8.052955
516	71.6	5.816023	75.92	10.289887
517	69.619995	5.816023	68	3.3553982
518	68	5.816023	68	5.816023
519	68	8.052955	68	3.3553982

520	71.6	5.816023	68	4.697557
521	77	4.697557	68	5.816023
522	78.8	4.697557	69.98	5.816023
523	80.6	4.697557	71.06	5.816023
524	82.4	8.052955	73.04	10.289887
525	80.6	6.9344893	75.02	10.289887
526	73.4	3.3553982	68	6.9344893
527	75.2	3.3553982	68	4.697557
528	68	4.697557	68	4.697557
529	71.6	5.816023	68	6.9344893
530	71.6	6.9344893	68	8.052955
531	77	9.171421	69.08	8.052955
532	72.32	6.9344893	71.96	6.9344893
533	68	4.697557	75.02	10.289887
534	69.8	3.3553982	73.94	9.171421
535	73.4	5.816023	71.06	10.289887
536	77	8.052955	68	6.9344893
537	80.6	6.9344893	68	8.052955
538	80.6	10.289887	68	8.052955
539	80.6	9.171421	69.08	3.3553982
540	80.6	3.3553982	71.96	4.697557
541	78.8	5.816023	75.92	3.3553982
542	68	5.816023	75.92	8.052955
543	78.8	3.3553982	75.92	9.171421
544	80.6	3.3553982	73.94	10.289887
545	78.8	4.697557	69.08	4.697557
546	75.2	5.816023	71.06	5.816023
547	71.6	6.9344893	71.96	8.052955
548	69.8	4.697557	68	5.816023
549	68	5.816023	69.08	6.9344893
550	77	6.9344893	69.98	10.289887
551	77	9.171421	69.98	10.289887
552	75.2	9.171421	69.08	6.9344893
553	77	9.171421	69.98	8.052955
554	75.2	9.171421	71.06	6.9344893
555	78.8	6.9344893	69.98	9.171421
556	75.2	5.816023	69.98	4.697557
557	72.32	5.368637	73.04	8.052955
558	69.8	4.697557	73.04	10.289887
559	69.8	5.816023	71.06	6.9344893
560	69.8	3.3553982	71.06	9.171421

561	71.6	3.3553982	73.04	8.052955
562	73.4	3.3553982	68	5.816023
563	78.8	3.3553982	69.98	8.052955
564	82.4	4.697557	71.96	3.3553982
565	78.8	4.697557	73.94	10.289887
566	75.92	5.368637	73.04	10.289887
567	73.4	5.816023	71.96	9.171421
568	71.6	3.3553982	71.06	10.289887
569	68	3.3553982	69.08	9.171421
570	75.2	6.9344893	68	6.9344893
571	77	4.697557	68	5.816023
572	78.8	3.3553982	68	5.816023
573	78.8	4.697557	68	3.3553982
574	81.32	6.9344893	68	10.289887
575	82.4	4.697557	68	9.171421
576	82.4	4.697557	68	9.171421
577	78.8	8.052955	68	9.171421
578	75.2	3.3553982	68	9.171421
579	71.6	3.3553982	68	8.052955
580	77	3.3553982	68	6.9344893
581	82.4	3.3553982	68	5.816023
582	81.32	4.697557	68	4.697557
583	80.6	6.9344893	69.08	5.816023
584	82.4	5.816023	69.98	5.816023
585	82.4	6.9344893	69.98	9.171421
586	80.6	5.816023	69.98	10.289887
587	77	4.697557	68	9.171421
588	75.2	3.3553982	68	8.052955
589	73.4	5.816023	69.08	10.289887
590	73.4	3.3553982	71.06	9.171421
591	69.8	3.3553982	71.06	8.052955
592	69.8	5.816023	68	3.3553982
593	73.4	5.816023	71.96	8.052955
594	77	6.9344893	71.96	9.171421
595	78.8	4.697557	71.06	9.171421
596	82.4	6.9344893	69.98	10.289887
597	82.4	4.697557	69.98	6.9344893
598	82.4	4.697557	69.08	4.697557
599	82.4	4.697557	69.08	5.816023
600	80.6	4.697557	69.08	3.3553982
601	75.2	4.697557	68	5.816023

602	73.4	3.3553982	68	5.816023
603	69.8	3.3553982	68	3.3553982
604	80.6	8.052955	73.04	3.3553982
605	80.6	4.697557	75.02	8.052955
606	77	3.3553982	75.02	9.171421
607	71.6	4.697557	75.92	9.171421
608	80.6	5.816023	75.92	10.289887
609	82.4	6.9344893	77	10.289887
610	80.6	6.9344893	73.94	9.171421
611	77	5.816023	71.06	9.171421
612	75.2	9.171421	71.06	5.816023
613	73.4	8.052955	71.06	5.816023
614	71.6	8.052955	71.06	3.3553982
615	69.8	3.3553982	71.06	6.9344893
616	69.8	5.816023	69.98	4.697557
617	71.6	3.3553982	69.98	4.697557
618	71.6	3.3553982	68	5.816023
619	75.2	9.171421	71.96	3.3553982
620	80.6	9.171421	75.92	3.3553982
621	82.4	6.9344893	78.08	8.052955
622	78.8	6.9344893	77	10.289887
623	71.6	4.697557	71.96	9.171421
624	72.14	4.697557	71.06	5.816023
625	71.6	4.697557	71.06	8.052955
626	71.6	4.697557	71.06	6.9344893
627	69.8	6.9344893	71.06	4.697557
628	75.2	3.3553982	69.98	5.816023
629	68.72	2.9080114	69.08	4.697557
630	68	4.697557	68	4.697557
631	71.6	6.9344893	73.94	4.697557
632	73.4	5.816023	75.02	5.816023
633	75.2	8.052955	80.06	6.9344893
634	75.2	6.9344893	82.04	9.171421
635	75.2	6.9344893	73.94	10.289887
636	75.2	5.816023	69.98	9.171421
637	77	5.816023	69.08	5.816023
638	77	5.816023	69.08	9.171421
639	75.2	3.3553982	69.08	5.816023
640	82.4	3.3553982	69.08	6.9344893
641	82.4	9.171421	68	3.3553982
642	78.8	9.171421	68	6.9344893

643	75.2	4.697557	68	3.3553982
644	71.6	3.3553982	68	3.3553982
645	69.8	3.3553982	71.96	5.816023
646	78.8	3.3553982	77	5.816023
647	80.6	6.9344893	75.02	10.289887
648	82.4	4.697557	68	8.052955
649	75.2	3.3553982	69.98	5.816023
650	73.4	3.3553982	71.06	9.171421
651	69.8	3.3553982	71.96	10.289887
652	78.8	5.816023	73.04	10.289887
653	80.6	5.816023	69.98	9.171421
654	80.6	3.3553982	68	6.9344893
655	78.8	3.3553982	69.98	8.052955
656	75.2	5.816023	71.06	9.171421
657	73.4	3.3553982	71.06	10.289887
658	69.8	4.697557	71.06	10.289887
659	68	4.697557	71.96	10.289887
660	77	8.052955	68	10.289887
661	80.6	6.9344893	68	3.3553982
662	82.4	6.9344893	73.04	5.816023
663	80.6	9.171421	73.94	10.289887
664	82.4	9.171421	73.04	9.171421
665	78.8	4.697557	69.08	9.171421
666	78.8	8.052955	71.06	6.9344893
667	78.8	3.3553982	71.06	8.052955
668	69.8	4.697557	69.08	10.289887
669	69.8	4.697557	69.08	6.9344893
670	73.4	5.816023	69.08	6.9344893
671	73.4	5.816023	69.08	10.289887
672	73.4	4.697557	69.08	9.171421
673	73.4	8.052955	69.08	9.171421
674	69.8	8.052955	69.08	10.289887
675	68	5.816023	69.08	9.171421
676	68	8.052955	68	6.9344893
677	68	6.9344893	69.08	8.052955
678	71.6	3.3553982	71.06	8.052955
679	71.6	4.697557	73.04	8.052955
680	71.6	3.3553982	73.04	9.171421
681	71.6	6.9344893	68	9.171421
682	69.8	5.816023	68	5.816023
683	69.8	8.052955	68	10.289887

684	68	5.816023	68	9.171421
685	68	5.816023	68	10.289887
686	68.36	6.487103	69.08	6.9344893
687	70.52	8.052955	71.06	8.052955
688	72.5	9.842502	73.94	3.3553982
689	75.2	10.289887	73.04	8.052955
690	76.46	9.171421	73.94	8.052955
691	76.82	8.052955	75.02	9.171421
692	77	6.9344893	75.02	9.171421
693	78.26	7.6055694	75.92	10.289887
694	78.8	8.052955	71.06	8.052955
695	75.2	4.697557	69.98	8.052955
696	71.6	5.816023	69.98	3.3553982
697	69.8	3.3553982	69.08	4.697557
698	68	4.697557	73.04	3.3553982
699	70.34	5.816023	78.08	5.816023
700	71.6	6.9344893	68	5.816023
701	73.76	6.487103	69.08	3.3553982
702	75.2	5.816023	69.08	5.816023
703	78.8	8.052955	68	6.9344893
704	78.8	9.171421	69.08	5.816023
705	78.8	9.171421	71.06	5.816023
706	77	8.052955	69.08	3.3553982
707	73.4	5.816023	71.06	4.697557
708	72.86	4.697557	80.06	5.816023
709	75.92	6.9344893	71.96	8.052955
710	78.8	9.171421	73.04	4.697557
711	78.8	8.052955	71.96	4.697557
712	82.4	4.697557	71.06	5.816023
713	82.4	9.171421	71.06	8.052955
714	82.4	6.9344893	69.98	4.697557
715	78.08	5.1449437	68	4.697557
716	72.14	3.5790913	68	4.697557
717	79.880005	2.6843185	68	3.3553982
718	82.4	3.3553982	71.06	3.3553982
719	78.8	6.9344893	75.92	4.697557
720	73.76	5.1449437	82.04	9.171421
721	69.8	3.5790913	75.92	10.289887
722	80.6	3.1317048	71.96	6.9344893
723	82.4	4.697557	71.96	6.9344893
724	82.4	8.052955	71.96	5.816023

725	78.8	5.816023	71.06	4.697557
726	74.66	2.9080114	69.98	5.816023
727	82.22	3.8027847	68	4.697557
728	82.4	8.052955	69.08	6.9344893
729	78.8	6.9344893	69.98	10.289887
730	75.2	4.697557	69.08	10.289887
731	71.6	3.3553982	69.08	10.289887
732	74.66	3.8027847	69.98	5.816023
733	77.72	4.2501707	71.06	9.171421
734	78.98	5.816023	69.98	10.289887
735	80.06	7.1581826	69.98	10.289887
736	80.42	8.724035	68	3.3553982
737	80.06	10.066195	69.98	6.9344893
738	80.6	10.289887	71.06	10.289887
739	80.6	10.289887	69.98	10.289887
740	80.24	8.500341	68	9.171421
741	79.16	6.9344893	69.98	4.697557
742	76.64	5.1449437	69.98	8.052955
743	74.66	3.3553982	68	9.171421
744	71.96	3.1317048	69.98	9.171421
745	71.6	4.697557	73.04	6.9344893
746	71.6	4.0264773	73.94	10.289887
747	71.6	3.3553982	75.02	8.052955
748	70.52	4.697557	68	5.816023
749	69.8	5.816023	69.98	6.9344893
750	68.36	5.1449437	69.98	9.171421
751	69.8	4.697557	69.98	5.816023
752	71.42	5.368637	71.06	8.052955
753	72.86	5.816023	69.98	10.289887
754	73.22	6.487103	68	9.171421
755	73.4	6.9344893	69.08	5.816023
756	72.86	7.6055694	73.94	4.697557
757	71.6	8.052955	77	6.9344893
758	72.14	6.0397167	78.98	6.9344893
759	72.14	4.0264773	78.08	9.171421
760	69.8	5.816023	71.06	6.9344893
761	69.8	4.697557	69.98	6.9344893
762	69.8	5.816023	68	6.9344893
763	69.98	2.9080114	68	5.816023
764	69.8	3.3553982	69.08	8.052955
765	69.619995	3.8027847	71.06	9.171421

766	69.8	4.2501707	68	5.816023
767	69.8	4.697557	69.98	6.9344893
768	69.8	3.3553982	69.98	8.052955
769	69.26	4.0264773	71.06	10.289887
770	68.18	4.697557	71.96	3.3553982
771	70.52	5.1449437	77	5.816023
772	73.4	5.816023	71.96	5.816023
773	73.4	5.816023	69.98	8.052955
774	75.380005	2.9080114	73.04	4.697557
775	73.4	5.816023	71.06	8.052955
776	76.46	4.697557	68	6.9344893
777	78.8	3.3553982	69.08	9.171421
778	79.7	3.5790913	68	6.9344893
779	79.7	3.8027847	68	3.3553982
780	79.16	4.2501707	69.08	10.289887
781	77.9	4.473864	69.08	5.816023
782	75.2	4.697557	69.08	5.816023
783	73.04	4.0264773	68	8.052955
784	71.6	3.3553982	68	6.9344893
785	71.06	2.6843185	69.08	10.289887
786	68	3.3553982	68	5.816023
787	72.86	2.4606254	69.98	9.171421
788	77	4.697557	68	10.289887
789	76.46	4.697557	75.02	6.9344893
790	75.2	4.697557	69.98	10.289887
791	75.56	6.487103	69.08	6.9344893
792	75.2	8.052955	68	5.816023
793	73.04	7.6055694	68	6.9344893
794	71.6	6.9344893	73.04	6.9344893
795	68	4.697557	75.92	9.171421
796	71.6	9.171421	82.04	6.9344893
797	74.119995	8.947728	80.06	9.171421
798	76.64	8.052955	77	9.171421
799	77.18	7.3818755	75.92	8.052955
800	79.7	6.487103	75.92	9.171421
801	80.42	6.487103	69.08	6.9344893
802	81.14	6.2634096	73.04	4.697557
803	81.68	6.0397167	68	6.9344893
804	78.8	5.816023	68	6.9344893
805	78.8	3.3553982	69.98	4.697557
806	76.82	3.3553982	69.98	5.816023

807	73.58	3.3553982	69.08	9.171421
808	70.7	3.3553982	69.98	10.289887
809	68.9	3.3553982	69.08	10.289887
810	71.06	4.921251	68	5.816023
811	74.84	6.7107964	69.08	9.171421
812	78.619995	6.2634096	69.08	4.697557
813	80.6	5.816023	69.08	8.052955
814	81.86	5.816023	69.98	8.052955
815	82.4	5.816023	71.06	4.697557
816	82.4	3.3553982	73.04	5.816023
817	82.4	3.3553982	71.96	10.289887
818	79.880005	2.4606254	71.06	5.816023
819	72.86	2.9080114	73.94	3.3553982
820	75.02	3.8027847	77	4.697557
821	76.1	4.921251	77	4.697557
822	77	5.816023	78.08	8.052955
823	78.08	6.0397167	78.08	4.697557
824	78.44	6.2634096	73.94	8.052955
825	78.619995	6.487103	71.06	5.816023
826	78.26	6.487103	68	8.052955
827	77	6.7107964	73.04	8.052955
828	75.2	6.9344893	75.92	8.052955
829	72.68	4.697557	78.98	6.9344893
830	68.18	3.8027847	80.06	8.052955
831	73.22	5.59233	71.06	5.816023
832	80.06	4.921251	75.02	4.697557
833	78.8	6.9344893	73.94	10.289887
834	79.34	6.487103	68	8.052955
835	79.880005	5.816023	68	9.171421
836	79.7	5.368637	68	6.9344893
837	78.8	4.697557	68	10.289887
838	77.72	4.2501707	68	4.697557
839	75.2	3.8027847	73.04	3.3553982
840	73.4	3.3553982	69.98	10.289887
841	71.96	3.5790913	71.96	8.052955
842	71.42	3.8027847	68	10.289887
843	70.34	4.0264773	71.96	6.9344893
844	69.98	4.0264773	75.02	6.9344893
845	69.8	4.2501707	78.08	4.697557
846	69.98	4.473864	69.08	8.052955
847	69.8	4.697557	68	5.816023

848	75.380005	2.4606254	71.06	4.697557
849	76.28	2.6843185	75.92	5.816023
850	76.64	3.1317048	75.92	6.9344893
851	71.42	2.6843185	75.02	8.052955
852	69.98	2.9080114	71.96	9.171421
853	68.36	4.0264773	69.98	9.171421
854	72.68	4.2501707	71.96	5.816023
855	74.66	6.9344893	77	6.9344893
856	75.92	9.618808	71.96	9.171421
857	76.82	9.842502	73.04	9.171421
858	79.16	7.6055694	73.04	9.171421
859	80.78	5.59233	75.02	4.697557
860	81.5	7.8292623	71.96	6.9344893
861	77.9	6.9344893	68	8.052955
862	75.02	3.8027847	68	8.052955
863	72.86	4.2501707	69.08	5.816023
864	71.6	4.473864	68	6.9344893
865	69.8	4.697557	69.98	6.9344893
866	69.8	5.368637	68	4.697557
867	69.8	5.816023	73.94	4.697557
868	69.26	3.8027847	78.98	4.697557
869	69.8	3.5790913	80.96	4.697557
870	69.8	6.9344893	82.04	8.052955
871	73.04	8.052955	80.06	6.9344893
872	75.2	9.171421	73.04	10.289887
873	77.54	9.842502	68	6.9344893
874	79.16	10.51358	69.08	3.3553982
875	77.54	9.618808	71.06	4.697557
876	74.3	7.8292623	71.06	6.9344893
877	71.6	6.2634096	71.96	9.171421
878	69.8	4.697557	71.06	10.289887
879	68.54	3.1317048	71.06	8.052955
880	69.8	4.697557	69.98	9.171421
881	73.22	7.3818755	68	8.052955
882	76.46	10.066195	68	8.052955
883	78.44	6.487103	69.08	10.289887
884	80.06	10.737274	69.08	8.052955
885	79.880005	9.395114	73.94	10.289887
886	77.9	5.816023	68	8.052955
887	75.92	5.59233	69.08	3.3553982
888	73.94	5.368637	69.98	9.171421

889	70.34	5.368637	69.08	5.816023
890	70.16	5.1449437	69.98	9.171421
891	68.18	4.921251	71.06	5.816023
892	69.26	10.289887	73.04	3.3553982
893	75.92	10.737274	68	10.289887
894	75.56	9.395114	69.08	4.697557
895	77.18	10.51358	68	10.289887
896	77.72	10.960967	71.06	6.9344893
897	73.94	9.171421	73.04	9.171421
898	68.36	7.8292623	75.02	4.697557
899	68.18	4.2501707	73.94	9.171421
900	71.6	4.697557	71.06	10.289887
901	74.3	4.697557	73.04	4.697557
902	76.46	4.697557	71.96	3.3553982
903	77.72	4.697557	68	4.697557
904	78.8	4.697557	69.08	6.9344893
905	78.26	4.921251	75.02	6.9344893
906	77	5.368637	78.08	4.697557
907	75.02	5.59233	80.06	4.697557
908	71.6	5.816023	78.08	10.289887
909	71.6	5.816023	69.98	10.289887
910	82.76	3.3553982	69.98	4.697557
911	80.6	3.3553982	69.08	6.9344893
912	75.92	2.4606254	71.06	6.9344893
913	71.6	3.3553982	78.08	5.816023
914	76.28	5.368637	80.96	9.171421
915	80.6	3.3553982	75.92	9.171421
916	82.76	3.8027847	71.96	9.171421
917	78.619995	3.3553982	71.06	8.052955
918	73.76	3.3553982	68	4.697557
919	69.8	3.3553982	69.08	5.816023
920	68.72	2.4606254	68	6.9344893
921	69.8	3.3553982	68	8.052955
922	74.119995	4.921251	71.96	6.9344893
923	78.26	6.2634096	77	6.9344893
924	81.32	7.8292623	80.06	4.697557
925	68.54	3.8027847	82.94	5.816023
926	71.96	4.921251	78.08	9.171421
927	75.2	5.816023	75.02	9.171421
928	78.98	6.2634096	73.04	6.9344893
929	81.68	6.487103	71.96	5.816023

930	80.6	3.3553982	75.92	6.9344893
931	77.36	3.3553982	78.98	3.3553982
932	75.02	3.3553982	71.96	10.289887
933	73.4	3.3553982	71.96	6.9344893
934	71.42	3.3553982	69.98	10.289887
935	70.16	3.3553982	71.06	3.3553982
936	69.08	3.3553982	73.04	4.697557
937	68.18	3.3553982	71.06	10.289887
938	71.6	8.052955	69.98	6.9344893
939	75.56	9.171421	69.98	6.9344893
940	79.52	10.289887	68	6.9344893
941	82.4	4.697557	68	5.816023
942	81.5	8.947728	68	3.3553982
943	78.8	9.171421	69.98	5.816023
944	76.64	7.6055694	69.08	10.289887
945	75.2	5.816023	75.02	4.697557
946	73.94	5.816023	73.04	4.697557
947	73.4	5.816023	77	3.3553982
948	75.2	6.9344893	71.06	4.697557
949	73.4	6.9344893	75.02	5.816023
950	72.32	6.487103	78.98	3.3553982
951	71.24	6.0397167	80.06	6.9344893
952	68.18	5.816023	80.06	9.171421
953	69.619995	5.816023	75.02	6.9344893
954	75.74	9.842502	71.06	6.9344893
955	76.28	10.737274	69.08	8.052955
956	82.04	6.9344893	71.06	6.9344893
957	79.16	6.2634096	71.96	3.3553982
958	77	4.697557	71.96	5.816023
959	74.84	4.473864		
960	72.14	4.473864		
961	70.34	4.2501707		
962	68.54	4.0264773		
963	69.8	4.697557		
964	73.76	5.368637		
965	77.72	6.2634096		
966	80.6	6.9344893		
967	69.98	6.9344893		
968	73.76	8.052955		
969	76.28	9.171421		
970	78.8	10.289887		

971	80.6	10.960967		
972	81.14	10.289887		
973	79.34	7.6055694		
974	76.1	5.1449437		
975	73.4	2.4606254		
976	75.2	4.697557		
977	78.08	4.697557		
978	80.6	4.697557		
979	81.68	4.2501707		
980	82.22	3.8027847		
981	82.4	3.3553982		
982	82.22	6.487103		
983	79.7	4.921251		
984	75.74	3.1317048		
985	73.04	6.2634096		
986	71.96	6.7107964		
987	72.68	7.3818755		
988	73.4	6.487103		
989	74.119995	3.5790913		
990	76.64	3.1317048		
991	77.36	6.9344893		
992	78.08	10.066195		
993	78.8	6.9344893		
994	80.6	6.7107964		
995	81.5	6.487103		
996	82.22	6.487103		
997	82.4	6.2634096		
998	81.86	6.0397167		
999	80.6	5.816023		
1000	69.8	5.816023		
1001	73.4	3.3553982		
1002	73.4	5.816023		
1003	77	4.697557		
1004	80.6	10.289887		
1005	77	6.9344893		
1006	78.8	4.697557		
1007	77	6.9344893		
1008	73.4	4.697557		
1009	68	3.3553982		
1010	68	4.697557		
1011	73.4	3.3553982		

1012	75.2	3.3553982		
1013	75.2	3.3553982		
1014	75.2	5.816023		
1015	69.8	4.697557		
1016	68	4.697557		
1017	69.8	3.3553982		
1018	69.8	3.3553982		
1019	71.6	4.697557		
1020	69.8	3.3553982		
1021	77	3.3553982		
1022	71.6	5.816023		
1023	78.8	3.3553982		
1024	68	10.289887		
1025	77	5.816023		
1026	78.8	3.3553982		
1027	78.8	4.697557		
1028	80.6	9.171421		
1029	78.8	5.816023		
1030	71.6	4.697557		
1031	71.6	4.697557		
1032	71.6	3.3553982		
1033	69.8	4.697557		
1034	69.8	4.697557		
1035	71.6	3.3553982		
1036	77	3.3553982		
1037	78.8	4.697557		
1038	80.6	4.697557		
1039	78.8	6.9344893		
1040	78.8	5.816023		
1041	75.2	3.3553982		
1042	75.2	5.816023		
1043	73.4	5.816023		
1044	71.6	3.3553982		
1045	69.8	4.697557		
1046	73.4	5.816023		
1047	75.2	6.9344893		
1048	78.8	3.3553982		
1049	82.4	4.697557		
1050	82.4	4.697557		
1051	69.8	3.3553982		
1052	71.6	8.052955		

1053	75.2	4.697557		
1054	78.8	4.697557		
1055	78.8	8.052955		
1056	78.8	5.816023		
1057	80.6	4.697557		
1058	80.6	6.9344893		
1059	82.4	5.816023		
1060	80.6	3.3553982		
1061	68	3.3553982		
1062	77	5.816023		
1063	78.8	8.052955		
1064	78.8	6.9344893		
1065	77.36	3.5790913		
1066	68	10.289887		
1067	68	5.816023		
1068	68	6.9344893		
1069	69.8	5.816023		
1070	68	10.289887		
1071	68	10.289887		
1072	71.6	10.289887		
1073	73.4	10.289887		
1074	75.2	9.171421		
1075	77	10.289887		
1076	78.8	8.052955		
1077	77	10.289887		
1078	75.2	6.9344893		
1079	71.6	6.9344893		
1080	71.6	4.697557		
1081	73.4	9.171421		
1082	77	6.9344893		
1083	78.8	6.9344893		
1084	80.6	9.171421		
1085	80.6	4.697557		
1086	78.8	6.9344893		
1087	77	9.171421		
1088	73.4	5.816023		
1089	71.6	5.816023		
1090	71.6	4.697557		
1091	71.6	5.816023		
1092	71.6	5.816023		
1093	71.6	3.3553982		

1094	71.6	9.171421		
1095	71.6	6.9344893		
1096	69.8	5.816023		
1097	73.4	10.289887		
1098	73.4	9.171421		
1099	69.8	5.816023		
1100	75.2	4.697557		
1101	77	4.697557		
1102	73.4	4.697557		
1103	71.6	10.289887		
1104	75.2	10.289887		
1105	78.8	10.289887		
1106	78.98	8.947728		
1107	78.44	7.6055694		
1108	77.18	6.0397167		
1109	75.2	4.697557		
1110	68	4.697557		
1111	78.8	3.3553982		
1112	80.6	6.9344893		
1113	71.6	5.816023		
1114	68	3.3553982		
1115	78.8	6.9344893		
1116	82.4	4.697557		
1117	82.4	3.3553982		
1118	82.4	4.697557		
1119	78.8	6.9344893		
1120	71.6	4.697557		
1121	73.4	5.816023		
1122	75.2	3.3553982		
1123	80.6	5.816023		
1124	82.4	4.697557		
1125	80.6	5.816023		
1126	75.2	8.052955		
1127	69.8	4.697557		
1128	69.8	6.9344893		
1129	78.8	4.697557		
1130	80.24	6.487103		
1131	80.42	8.500341		
1132	80.6	10.289887		
1133	75.2	8.052955		
1134	69.8	6.9344893		

1135	68	4.697557		
1136	69.8	3.3553982		
1137	69.8	4.697557		
1138	69.8	6.9344893		
1139	71.6	6.9344893		
1140	71.6	9.171421		
1141	69.8	8.052955		
1142	68	5.816023		
1143	68	3.3553982		
1144	68	4.697557		
1145	68	6.9344893		
1146	68	6.9344893		
1147	68	6.9344893		
1148	69.8	6.9344893		
1149	69.8	6.9344893		
1150	73.4	9.171421		
1151	73.4	10.289887		
1152	75.2	8.052955		
1153	73.4	10.289887		
1154	71.6	5.816023		
1155	69.8	6.9344893		
1156	68	8.052955		
1157	68	10.289887		
1158	68	8.052955		
1159	68	6.9344893		
1160	68	9.171421		
1161	68	8.052955		
1162	68	6.9344893		
1163	69.8	4.697557		
1164	69.8	6.9344893		
1165	69.8	4.697557		
1166	69.8	3.3553982		
1167	71.6	3.3553982		
1168	71.6	3.3553982		
1169	71.6	3.3553982		
1170	71.6	3.3553982		
1171	68	3.3553982		
1172	68	5.816023		
1173	71.6	8.052955		
1174	68	9.171421		
1175	71.6	4.697557		

1176	71.6	3.3553982		
1177	71.6	3.3553982		
1178	69.8	4.697557		
1179	68	5.816023		
1180	68	4.697557		
1181	69.8	4.697557		
1182	69.8	5.816023		
1183	69.8	4.697557		
1184	69.8	3.3553982		
1185	71.6	5.816023		
1186	69.8	8.052955		
1187	68	3.3553982		
1188	71.6	8.052955		
1189	73.4	9.171421		
1190	75.2	3.3553982		
1191	73.4	6.9344893		
1192	73.4	9.171421		
1193	69.8	9.171421		
1194	69.8	10.289887		
1195	68	8.052955		
1196	68	9.171421		
1197	69.8	9.171421		
1198	68	8.052955		
1199	73.4	10.289887		
1200	69.8	10.289887		
1201	75.2	8.052955		
1202	77	9.171421		
1203	75.2	10.289887		
1204	75.2	8.052955		
1205	71.6	6.9344893		
1206	69.8	6.9344893		
1207	68	3.3553982		
1208	73.4	6.9344893		
1209	75.2	9.171421		
1210	80.6	8.052955		
1211	82.4	4.697557		
1212	68	3.3553982		
1213	73.4	4.697557		
1214	78.8	5.816023		
1215	80.6	8.052955		
1216	82.4	4.697557		

1217	80.6	3.3553982		
1218	78.8	3.3553982		
1219	80.6	6.9344893		
1220	75.2	3.3553982		
1221	69.8	5.816023		
1222	69.8	8.052955		
1223	71.6	6.9344893		
1224	71.6	5.816023		
1225	69.8	4.697557		
1226	71.6	3.3553982		
1227	71.6	3.3553982		
1228	69.8	3.3553982		
1229	69.8	4.697557		
1230	73.4	3.3553982		
1231	77	3.3553982		
1232	80.6	3.3553982		
1233	80.6	5.816023		
1234	78.8	6.9344893		
1235	73.4	4.697557		
1236	69.8	3.3553982		
1237	68	3.3553982		
1238	75.2	4.697557		
1239	77.9	9.842502		
1240	78.8	10.289887		
1241	77	10.289887		
1242	73.4	9.171421		
1243	69.8	8.052955		
1244	69.8	4.697557		
1245	68	3.3553982		
1246	69.8	3.3553982		
1247	69.8	4.697557		
1248	68	3.3553982		
1249	68	8.052955		
1250	71.6	6.9344893		
1251	71.6	3.3553982		
1252	71.6	4.697557		

9.2 Appendix B: The Full Generated Data Sets for the Target Natural Case and the Two Best Experimental Cases

Table 29: The Full Generated Data Sets for the Target Natural Case and the Two Best Experimental Cases.

	Blacksburg's Filtered Airflow Velocity (mph)	Vertical Scenario Airflow Velocity (mph)	Horizontal Scenario Airflow Velocity (mph)
1	10.29	10.26	10.24
2	9.17	9.2	9.18
3	9.17	9.2	9.18
4	8.05	8.06	8.13
5	10.29	10.26	10.24
6	6.71	6.75	6.72
7	8.05	8.06	8.13
8	6.71	6.75	6.72
9	10.29	10.26	10.24
10	6.71	6.75	6.72
11	9.17	9.2	9.18
12	9.17	9.2	9.18
13	10.29	10.26	10.24
14	6.71	6.75	6.72
15	5.59	5.59	5.62
16	8.05	8.06	8.13
17	10.29	10.26	10.24
18	8.05	8.06	8.13
19	4.47	4.54	4.48
20	3.36	3.4	3.41
21	5.59	5.59	5.62
22	6.71	6.75	6.72
23	10.29	10.26	10.24
24	9.17	9.2	9.18
25	10.29	10.26	10.24
26	8.05	8.06	8.13
27	9.17	9.2	9.18
28	10.29	10.26	10.24

29	3.36	3.4	3.41
30	8.05	8.06	8.13
31	5.59	5.59	5.62
32	3.36	3.4	3.41
33	4.47	4.54	4.48
34	5.59	5.59	5.62
35	5.59	5.59	5.62
36	10.29	10.26	10.24
37	8.05	8.06	8.13
38	10.29	10.26	10.24
39	9.17	9.2	9.18
40	5.59	5.59	5.62
41	5.59	5.59	5.62
42	4.47	4.54	4.48
43	4.47	4.54	4.48
44	4.7	4.65	4.71
45	4.7	4.65	4.71
46	4.7	4.65	4.71
47	9.17	9.2	9.18
48	9.17	9.2	9.18
49	8.05	8.06	8.13
50	5.82	5.81	5.82
51	6.93	6.98	6.92
52	3.36	3.4	3.41
53	3.36	3.4	3.41
54	8.05	8.06	8.13
55	8.05	8.06	8.13
56	3.36	3.4	3.41
57	6.93	6.98	6.92
58	9.17	9.2	9.18
59	10.29	10.26	10.24
60	8.05	8.06	8.13
61	4.7	4.65	4.71
62	6.93	6.98	6.92
63	3.36	3.4	3.41
64	6.93	6.98	6.92
65	9.17	9.2	9.18
66	6.93	6.98	6.92
67	9.17	9.2	9.18
68	10.29	10.26	10.24
69	9.17	9.2	9.18

70	3.36	3.4	3.41
71	5.82	5.81	5.82
72	4.7	4.65	4.71
73	5.82	5.81	5.82
74	5.82	5.81	5.82
75	3.36	3.4	3.41
76	5.82	5.81	5.82
77	5.82	5.81	5.82
78	8.05	8.06	8.13
79	6.93	6.98	6.92
80	8.05	8.06	8.13
81	9.17	9.2	9.18
82	5.82	5.81	5.82
83	8.05	8.06	8.13
84	4.7	4.65	4.71
85	3.36	3.4	3.41
86	8.05	8.06	8.13
87	9.17	9.2	9.18
88	10.96	0	0
89	8.05	8.06	8.13
90	10.29	10.26	10.24
91	8.05	8.06	8.13
92	5.82	5.81	5.82
93	8.05	8.06	8.13
94	9.17	9.2	9.18
95	7.61	7.6	7.61
96	4.7	4.65	4.71
97	5.37	5.39	5.41
98	5.82	5.81	5.82
99	9.17	9.2	9.18
100	9.17	9.2	9.18
101	5.82	5.81	5.82
102	6.93	6.98	6.92
103	8.05	8.06	8.13
104	9.17	9.2	9.18
105	9.17	9.2	9.18
106	5.37	5.39	5.41
107	8.05	8.06	8.13
108	9.17	9.2	9.18
109	8.05	8.06	8.13
110	10.29	10.26	10.24

111	8.05	8.06	8.13
112	5.82	5.81	5.82
113	5.82	5.81	5.82
114	6.93	6.98	6.92
115	6.93	6.98	6.92
116	3.36	3.4	3.41
117	6.93	6.98	6.92
118	6.93	6.98	6.92
119	6.93	6.98	6.92
120	8.05	8.06	8.13
121	6.93	6.98	6.92
122	10.29	10.26	10.24
123	8.05	8.06	8.13
124	6.93	6.98	6.92
125	8.05	8.06	8.13
126	6.49	6.47	6.46
127	3.36	3.4	3.41
128	6.93	6.98	6.92
129	8.05	8.06	8.13
130	5.82	5.81	5.82
131	5.82	5.81	5.82
132	3.36	3.4	3.41
133	3.36	3.4	3.41
134	6.93	6.98	6.92
135	8.05	8.06	8.13
136	8.05	8.06	8.13
137	4.7	4.65	4.71
138	4.7	4.65	4.71
139	3.36	3.4	3.41
140	5.82	5.81	5.82
141	4.7	4.65	4.71
142	4.7	4.65	4.71
143	9.17	9.2	9.18
144	6.93	6.98	6.92
145	8.05	8.06	8.13
146	9.17	9.2	9.18
147	6.93	6.98	6.92
148	8.05	8.06	8.13
149	8.05	8.06	8.13
150	8.05	8.06	8.13
151	4.7	4.65	4.71

152	4.03	4.06	4.02
153	3.36	3.4	3.41
154	4.7	4.65	4.71
155	8.05	8.06	8.13
156	6.93	6.98	6.92
157	5.82	5.81	5.82
158	3.36	3.4	3.41
159	3.58	3.59	3.53
160	6.93	6.98	6.92
161	6.93	6.98	6.92
162	4.7	4.65	4.71
163	6.93	6.98	6.92
164	6.93	6.98	6.92
165	3.36	3.4	3.41
166	5.82	5.81	5.82
167	8.05	8.06	8.13
168	6.93	6.98	6.92
169	8.05	8.06	8.13
170	5.82	5.81	5.82
171	4.7	4.65	4.71
172	3.36	3.4	3.41
173	3.36	3.4	3.41
174	5.82	5.81	5.82
175	8.05	8.06	8.13
176	9.17	9.2	9.18
177	10.29	10.26	10.24
178	5.82	5.81	5.82
179	4.7	4.65	4.71
180	4.03	4.06	4.02
181	4.7	4.65	4.71
182	8.05	8.06	8.13
183	9.17	9.2	9.18
184	8.05	8.06	8.13
185	6.93	6.98	6.92
186	10.29	10.26	10.24
187	10.29	10.26	10.24
188	6.93	6.98	6.92
189	6.93	6.98	6.92
190	6.93	6.98	6.92
191	4.7	4.65	4.71
192	4.7	4.65	4.71

193	3.36	3.4	3.41
194	6.93	6.98	6.92
195	6.93	6.98	6.92
196	6.93	6.98	6.92
197	9.17	9.2	9.18
198	8.05	8.06	8.13
199	8.72	8.66	8.75
200	9.17	9.2	9.18
201	6.93	6.98	6.92
202	3.58	3.59	3.53
203	6.93	6.98	6.92
204	6.93	6.98	6.92
205	6.93	6.98	6.92
206	8.05	8.06	8.13
207	6.93	6.98	6.92
208	8.05	8.06	8.13
209	5.59	5.59	5.62
210	4.47	4.54	4.48
211	5.59	5.59	5.62
212	4.47	4.54	4.48
213	8.05	8.06	8.13
214	8.05	8.06	8.13
215	8.05	8.06	8.13
216	6.71	6.75	6.72
217	5.59	5.59	5.62
218	8.05	8.06	8.13
219	4.47	4.54	4.48
220	8.05	8.06	8.13
221	9.17	9.2	9.18
222	5.59	5.59	5.62
223	9.17	9.2	9.18
224	6.71	6.75	6.72
225	6.71	6.75	6.72
226	5.59	5.59	5.62
227	4.47	4.54	4.48
228	5.59	5.59	5.62
229	5.59	5.59	5.62
230	3.36	3.4	3.41
231	4.47	4.54	4.48
232	8.05	8.06	8.13
233	9.17	9.2	9.18

234	4.47	4.54	4.48
235	8.05	8.06	8.13
236	6.71	6.75	6.72
237	3.36	3.4	3.41
238	3.36	3.4	3.41
239	3.36	3.4	3.41
240	5.59	5.59	5.62
241	3.36	3.4	3.41
242	4.47	4.54	4.48
243	4.47	4.54	4.48
244	4.47	4.54	4.48
245	4.47	4.54	4.48
246	4.47	4.54	4.48
247	3.36	3.4	3.41
248	4.47	4.54	4.48
249	5.59	5.59	5.62
250	3.36	3.4	3.41
251	4.47	4.54	4.48
252	5.59	5.59	5.62
253	3.36	3.4	3.41
254	3.36	3.4	3.41
255	6.71	6.75	6.72
256	8.05	8.06	8.13
257	6.71	6.75	6.72
258	8.05	8.06	8.13
259	8.05	8.06	8.13
260	10.29	10.26	10.24
261	9.17	9.2	9.18
262	8.05	8.06	8.13
263	9.17	9.2	9.18
264	8.05	8.06	8.13
265	8.05	8.06	8.13
266	9.17	9.2	9.18
267	10.29	10.26	10.24
268	9.17	9.2	9.18
269	8.05	8.06	8.13
270	6.71	6.75	6.72
271	5.59	5.59	5.62
272	4.47	4.54	4.48
273	4.47	4.54	4.48
274	5.59	5.59	5.62

275	6.71	6.75	6.72
276	3.36	3.4	3.41
277	9.17	9.2	9.18
278	6.71	6.75	6.72
279	4.47	4.54	4.48
280	4.47	4.54	4.48
281	6.71	6.75	6.72
282	4.47	4.54	4.48
283	4.47	4.54	4.48
284	6.71	6.75	6.72
285	6.71	6.75	6.72
286	8.05	8.06	8.13
287	9.17	9.2	9.18
288	6.71	6.75	6.72
289	8.05	8.06	8.13
290	5.59	5.59	5.62
291	6.71	6.75	6.72
292	6.71	6.75	6.72
293	8.05	8.06	8.13
294	6.71	6.75	6.72
295	9.17	9.2	9.18
296	10.29	10.26	10.24
297	8.05	8.06	8.13
298	10.29	10.26	10.24
299	6.71	6.75	6.72
300	4.47	4.54	4.48
301	4.47	4.54	4.48
302	4.47	4.54	4.48
303	4.47	4.54	4.48
304	5.59	5.59	5.62
305	5.59	5.59	5.62
306	6.71	6.75	6.72
307	5.59	5.59	5.62
308	4.47	4.54	4.48
309	3.36	3.4	3.41
310	3.36	3.4	3.41
311	5.59	5.59	5.62
312	3.36	3.4	3.41
313	3.36	3.4	3.41
314	8.05	8.06	8.13
315	3.36	3.4	3.41

316	4.47	4.54	4.48
317	10.29	10.26	10.24
318	9.17	9.2	9.18
319	6.71	6.75	6.72
320	4.47	4.54	4.48
321	4.47	4.54	4.48
322	4.47	4.54	4.48
323	3.36	3.4	3.41
324	3.36	3.4	3.41
325	3.36	3.4	3.41
326	9.17	9.2	9.18
327	5.59	5.59	5.62
328	5.59	5.59	5.62
329	3.36	3.4	3.41
330	3.36	3.4	3.41
331	3.36	3.4	3.41
332	4.47	4.54	4.48
333	5.59	5.59	5.62
334	10.29	10.26	10.24
335	4.47	4.54	4.48
336	3.36	3.4	3.41
337	3.36	3.4	3.41
338	5.59	5.59	5.62
339	4.47	4.54	4.48
340	3.36	3.4	3.41
341	3.36	3.4	3.41
342	4.47	4.54	4.48
343	3.36	3.4	3.41
344	9.17	9.2	9.18
345	8.05	8.06	8.13
346	3.36	3.4	3.41
347	5.59	5.59	5.62
348	4.47	4.54	4.48
349	5.59	5.59	5.62
350	8.05	8.06	8.13
351	4.47	4.54	4.48
352	8.05	8.06	8.13
353	10.29	10.26	10.24
354	5.59	5.59	5.62
355	8.05	8.06	8.13
356	5.59	5.59	5.62

357	3.36	3.4	3.41
358	4.47	4.54	4.48
359	6.26	6.28	6.28
360	8.05	8.06	8.13
361	9.17	9.2	9.18
362	6.71	6.75	6.72
363	8.05	8.06	8.13
364	10.29	10.26	10.24
365	6.71	6.75	6.72
366	9.17	9.2	9.18
367	9.17	9.2	9.18
368	9.17	9.2	9.18
369	5.59	5.59	5.62
370	9.17	9.2	9.18
371	5.59	5.59	5.62
372	4.47	4.54	4.48
373	5.59	5.59	5.62
374	5.59	5.59	5.62
375	9.17	9.2	9.18
376	10.29	10.26	10.24
377	6.71	6.75	6.72
378	4.47	4.54	4.48
379	5.59	5.59	5.62
380	8.05	8.06	8.13
381	6.71	6.75	6.72
382	3.36	3.4	3.41
383	3.36	3.4	3.41
384	8.05	8.06	8.13
385	9.17	9.2	9.18
386	10.29	10.26	10.24
387	9.17	9.2	9.18
388	10.29	10.26	10.24
389	8.05	8.06	8.13
390	9.17	9.2	9.18
391	8.05	8.06	8.13
392	10.29	10.26	10.24
393	9.17	9.2	9.18
394	5.59	5.59	5.62
395	5.59	5.59	5.62
396	3.36	3.4	3.41
397	3.36	3.4	3.41

398	4.47	4.54	4.48
399	4.47	4.54	4.48
400	6.71	6.75	6.72
401	10.29	10.26	10.24
402	8.05	8.06	8.13
403	9.17	9.2	9.18
404	8.05	8.06	8.13
405	6.71	6.75	6.72
406	4.47	4.54	4.48
407	3.36	3.4	3.41
408	6.71	6.75	6.72
409	9.17	9.2	9.18
410	10.29	10.26	10.24
411	8.05	8.06	8.13
412	10.29	10.26	10.24
413	4.47	4.54	4.48
414	6.71	6.75	6.72
415	6.71	6.75	6.72
416	3.36	3.4	3.41
417	3.36	3.4	3.41
418	10.29	10.26	10.24
419	4.47	4.54	4.48
420	6.71	6.75	6.72
421	5.59	5.59	5.62
422	3.36	3.4	3.41
423	3.36	3.4	3.41
424	3.36	3.4	3.41
425	4.47	4.54	4.48
426	4.47	4.54	4.48
427	3.36	3.4	3.41
428	4.47	4.54	4.48
429	3.36	3.4	3.41
430	4.47	4.54	4.48
431	3.36	3.4	3.41
432	4.47	4.54	4.48
433	4.47	4.54	4.48
434	4.47	4.54	4.48
435	4.47	4.54	4.48
436	4.47	4.54	4.48
437	3.36	3.4	3.41
438	3.36	3.4	3.41

439	3.36	3.4	3.41
440	4.47	4.54	4.48
441	5.59	5.59	5.62
442	4.47	4.54	4.48
443	3.36	3.4	3.41
444	3.36	3.4	3.41
445	4.47	4.54	4.48
446	6.71	6.75	6.72
447	9.17	9.2	9.18
448	7.61	7.6	7.61
449	5.14	5.12	5.17
450	4.7	4.65	4.71
451	8.05	8.06	8.13
452	9.17	9.2	9.18
453	4.7	4.65	4.71
454	6.93	6.98	6.92
455	5.82	5.81	5.82
456	6.93	6.98	6.92
457	3.36	3.4	3.41
458	8.05	8.06	8.13
459	10.29	10.26	10.24
460	9.17	9.2	9.18
461	6.93	6.98	6.92
462	5.82	5.81	5.82
463	2.91	2.87	2.88
464	6.93	6.98	6.92
465	5.82	5.81	5.82
466	4.7	4.65	4.71
467	4.7	4.65	4.71
468	4.7	4.65	4.71
469	9.17	9.2	9.18
470	2.91	2.87	2.88
471	5.82	5.81	5.82
472	6.93	6.98	6.92
473	6.93	6.98	6.92
474	3.36	3.4	3.41
475	6.93	6.98	6.92
476	2.46	2.41	2.47
477	4.7	4.65	4.71
478	4.7	4.65	4.71
479	6.93	6.98	6.92

480	6.93	6.98	6.92
481	6.93	6.98	6.92
482	4.7	4.65	4.71
483	9.17	9.2	9.18
484	4.7	4.65	4.71
485	6.93	6.98	6.92
486	3.36	3.4	3.41
487	4.7	4.65	4.71
488	3.36	3.4	3.41
489	3.36	3.4	3.41
490	3.36	3.4	3.41
491	3.36	3.4	3.41
492	3.36	3.4	3.41
493	3.36	3.4	3.41
494	6.93	6.98	6.92
495	8.05	8.06	8.13
496	4.7	4.65	4.71
497	9.17	9.2	9.18
498	4.7	4.65	4.71
499	3.36	3.4	3.41
500	3.36	3.4	3.41
501	8.05	8.06	8.13
502	5.82	5.81	5.82
503	9.17	9.2	9.18
504	6.93	6.98	6.92
505	3.36	3.4	3.41
506	3.36	3.4	3.41
507	4.7	4.65	4.71
508	3.36	3.4	3.41
509	3.36	3.4	3.41
510	6.93	6.98	6.92
511	10.29	10.26	10.24
512	8.05	8.06	8.13
513	3.36	3.4	3.41
514	6.93	6.98	6.92
515	6.93	6.98	6.92
516	5.82	5.81	5.82
517	5.82	5.81	5.82
518	5.82	5.81	5.82
519	8.05	8.06	8.13
520	5.82	5.81	5.82

521	4.7	4.65	4.71
522	4.7	4.65	4.71
523	4.7	4.65	4.71
524	8.05	8.06	8.13
525	6.93	6.98	6.92
526	3.36	3.4	3.41
527	3.36	3.4	3.41
528	4.7	4.65	4.71
529	5.82	5.81	5.82
530	6.93	6.98	6.92
531	9.17	9.2	9.18
532	6.93	6.98	6.92
533	4.7	4.65	4.71
534	3.36	3.4	3.41
535	5.82	5.81	5.82
536	8.05	8.06	8.13
537	6.93	6.98	6.92
538	10.29	10.26	10.24
539	9.17	9.2	9.18
540	3.36	3.4	3.41
541	5.82	5.81	5.82
542	5.82	5.81	5.82
543	3.36	3.4	3.41
544	3.36	3.4	3.41
545	4.7	4.65	4.71
546	5.82	5.81	5.82
547	6.93	6.98	6.92
548	4.7	4.65	4.71
549	5.82	5.81	5.82
550	6.93	6.98	6.92
551	9.17	9.2	9.18
552	9.17	9.2	9.18
553	9.17	9.2	9.18
554	9.17	9.2	9.18
555	6.93	6.98	6.92
556	5.82	5.81	5.82
557	5.37	5.39	5.41
558	4.7	4.65	4.71
559	5.82	5.81	5.82
560	3.36	3.4	3.41
561	3.36	3.4	3.41

562	3.36	3.4	3.41
563	3.36	3.4	3.41
564	4.7	4.65	4.71
565	4.7	4.65	4.71
566	5.37	5.39	5.41
567	5.82	5.81	5.82
568	3.36	3.4	3.41
569	3.36	3.4	3.41
570	6.93	6.98	6.92
571	4.7	4.65	4.71
572	3.36	3.4	3.41
573	4.7	4.65	4.71
574	6.93	6.98	6.92
575	4.7	4.65	4.71
576	4.7	4.65	4.71
577	8.05	8.06	8.13
578	3.36	3.4	3.41
579	3.36	3.4	3.41
580	3.36	3.4	3.41
581	3.36	3.4	3.41
582	4.7	4.65	4.71
583	6.93	6.98	6.92
584	5.82	5.81	5.82
585	6.93	6.98	6.92
586	5.82	5.81	5.82
587	4.7	4.65	4.71
588	3.36	3.4	3.41
589	5.82	5.81	5.82
590	3.36	3.4	3.41
591	3.36	3.4	3.41
592	5.82	5.81	5.82
593	5.82	5.81	5.82
594	6.93	6.98	6.92
595	4.7	4.65	4.71
596	6.93	6.98	6.92
597	4.7	4.65	4.71
598	4.7	4.65	4.71
599	4.7	4.65	4.71
600	4.7	4.65	4.71
601	4.7	4.65	4.71
602	3.36	3.4	3.41

603	3.36	3.4	3.41
604	8.05	8.06	8.13
605	4.7	4.65	4.71
606	3.36	3.4	3.41
607	4.7	4.65	4.71
608	5.82	5.81	5.82
609	6.93	6.98	6.92
610	6.93	6.98	6.92
611	5.82	5.81	5.82
612	9.17	9.2	9.18
613	8.05	8.06	8.13
614	8.05	8.06	8.13
615	3.36	3.4	3.41
616	5.82	5.81	5.82
617	3.36	3.4	3.41
618	3.36	3.4	3.41
619	9.17	9.2	9.18
620	9.17	9.2	9.18
621	6.93	6.98	6.92
622	6.93	6.98	6.92
623	4.7	4.65	4.71
624	4.7	4.65	4.71
625	4.7	4.65	4.71
626	4.7	4.65	4.71
627	6.93	6.98	6.92
628	3.36	3.4	3.41
629	2.91	2.87	2.88
630	4.7	4.65	4.71
631	6.93	6.98	6.92
632	5.82	5.81	5.82
633	8.05	8.06	8.13
634	6.93	6.98	6.92
635	6.93	6.98	6.92
636	5.82	5.81	5.82
637	5.82	5.81	5.82
638	5.82	5.81	5.82
639	3.36	3.4	3.41
640	3.36	3.4	3.41
641	9.17	9.2	9.18
642	9.17	9.2	9.18
643	4.7	4.65	4.71

644	3.36	3.4	3.41
645	3.36	3.4	3.41
646	3.36	3.4	3.41
647	6.93	6.98	6.92
648	4.7	4.65	4.71
649	3.36	3.4	3.41
650	3.36	3.4	3.41
651	3.36	3.4	3.41
652	5.82	5.81	5.82
653	5.82	5.81	5.82
654	3.36	3.4	3.41
655	3.36	3.4	3.41
656	5.82	5.81	5.82
657	3.36	3.4	3.41
658	4.7	4.65	4.71
659	4.7	4.65	4.71
660	8.05	8.06	8.13
661	6.93	6.98	6.92
662	6.93	6.98	6.92
663	9.17	9.2	9.18
664	9.17	9.2	9.18
665	4.7	4.65	4.71
666	8.05	8.06	8.13
667	3.36	3.4	3.41
668	4.7	4.65	4.71
669	4.7	4.65	4.71
670	5.82	5.81	5.82
671	5.82	5.81	5.82
672	4.7	4.65	4.71
673	8.05	8.06	8.13
674	8.05	8.06	8.13
675	5.82	5.81	5.82
676	8.05	8.06	8.13
677	6.93	6.98	6.92
678	3.36	3.4	3.41
679	4.7	4.65	4.71
680	3.36	3.4	3.41
681	6.93	6.98	6.92
682	5.82	5.81	5.82
683	8.05	8.06	8.13
684	5.82	5.81	5.82

685	5.82	5.81	5.82
686	6.49	6.47	6.46
687	8.05	8.06	8.13
688	9.84	9.78	9.84
689	10.29	10.26	10.24
690	9.17	9.2	9.18
691	8.05	8.06	8.13
692	6.93	6.98	6.92
693	7.61	7.6	7.61
694	8.05	8.06	8.13
695	4.7	4.65	4.71
696	5.82	5.81	5.82
697	3.36	3.4	3.41
698	4.7	4.65	4.71
699	5.82	5.81	5.82
700	6.93	6.98	6.92
701	6.49	6.47	6.46
702	5.82	5.81	5.82
703	8.05	8.06	8.13
704	9.17	9.2	9.18
705	9.17	9.2	9.18
706	8.05	8.06	8.13
707	5.82	5.81	5.82
708	4.7	4.65	4.71
709	6.93	6.98	6.92
710	9.17	9.2	9.18
711	8.05	8.06	8.13
712	4.7	4.65	4.71
713	9.17	9.2	9.18
714	6.93	6.98	6.92
715	5.14	5.12	5.17
716	3.58	3.59	3.53
717	2.68	2.64	2.59
718	3.36	3.4	3.41
719	6.93	6.98	6.92
720	5.14	5.12	5.17
721	3.58	3.59	3.53
722	3.13	3.12	3.12
723	4.7	4.65	4.71
724	8.05	8.06	8.13
725	5.82	5.81	5.82

726	2.91	2.87	2.88
727	3.8	3.83	3.83
728	8.05	8.06	8.13
729	6.93	6.98	6.92
730	4.7	4.65	4.71
731	3.36	3.4	3.41
732	3.8	3.83	3.83
733	4.25	4.23	4.3
734	5.82	5.81	5.82
735	7.16	7.16	7.16
736	8.72	8.66	8.75
737	10.07	10.08	9.96
738	10.29	10.26	10.24
739	10.29	10.26	10.24
740	8.5	8.53	8.48
741	6.93	6.98	6.92
742	5.14	5.12	5.17
743	3.36	3.4	3.41
744	3.13	3.12	3.12
745	4.7	4.65	4.71
746	4.03	4.06	4.02
747	3.36	3.4	3.41
748	4.7	4.65	4.71
749	5.82	5.81	5.82
750	5.14	5.12	5.17
751	4.7	4.65	4.71
752	5.37	5.39	5.41
753	5.82	5.81	5.82
754	6.49	6.47	6.46
755	6.93	6.98	6.92
756	7.61	7.6	7.61
757	8.05	8.06	8.13
758	6.04	6.11	6.06
759	4.03	4.06	4.02
760	5.82	5.81	5.82
761	4.7	4.65	4.71
762	5.82	5.81	5.82
763	2.91	2.87	2.88
764	3.36	3.4	3.41
765	3.8	3.83	3.83
766	4.25	4.23	4.3

767	4.7	4.65	4.71
768	3.36	3.4	3.41
769	4.03	4.06	4.02
770	4.7	4.65	4.71
771	5.14	5.12	5.17
772	5.82	5.81	5.82
773	5.82	5.81	5.82
774	2.91	2.87	2.88
775	5.82	5.81	5.82
776	4.7	4.65	4.71
777	3.36	3.4	3.41
778	3.58	3.59	3.53
779	3.8	3.83	3.83
780	4.25	4.23	4.3
781	4.47	4.54	4.48
782	4.7	4.65	4.71
783	4.03	4.06	4.02
784	3.36	3.4	3.41
785	2.68	2.64	2.59
786	3.36	3.4	3.41
787	2.46	2.41	2.47
788	4.7	4.65	4.71
789	4.7	4.65	4.71
790	4.7	4.65	4.71
791	6.49	6.47	6.46
792	8.05	8.06	8.13
793	7.61	7.6	7.61
794	6.93	6.98	6.92
795	4.7	4.65	4.71
796	9.17	9.2	9.18
797	8.95	9.07	8.95
798	8.05	8.06	8.13
799	7.38	7.37	7.32
800	6.49	6.47	6.46
801	6.49	6.47	6.46
802	6.26	6.28	6.28
803	6.04	6.11	6.06
804	5.82	5.81	5.82
805	3.36	3.4	3.41
806	3.36	3.4	3.41
807	3.36	3.4	3.41

808	3.36	3.4	3.41
809	3.36	3.4	3.41
810	4.92	4.94	4.94
811	6.71	6.75	6.72
812	6.26	6.28	6.28
813	5.82	5.81	5.82
814	5.82	5.81	5.82
815	5.82	5.81	5.82
816	3.36	3.4	3.41
817	3.36	3.4	3.41
818	2.46	2.41	2.47
819	2.91	2.87	2.88
820	3.8	3.83	3.83
821	4.92	4.94	4.94
822	5.82	5.81	5.82
823	6.04	6.11	6.06
824	6.26	6.28	6.28
825	6.49	6.47	6.46
826	6.49	6.47	6.46
827	6.71	6.75	6.72
828	6.93	6.98	6.92
829	4.7	4.65	4.71
830	3.8	3.83	3.83
831	5.59	5.59	5.62
832	4.92	4.94	4.94
833	6.93	6.98	6.92
834	6.49	6.47	6.46
835	5.82	5.81	5.82
836	5.37	5.39	5.41
837	4.7	4.65	4.71
838	4.25	4.23	4.3
839	3.8	3.83	3.83
840	3.36	3.4	3.41
841	3.58	3.59	3.53
842	3.8	3.83	3.83
843	4.03	4.06	4.02
844	4.03	4.06	4.02
845	4.25	4.23	4.3
846	4.47	4.54	4.48
847	4.7	4.65	4.71
848	2.46	2.41	2.47

849	2.68	2.64	2.59
850	3.13	3.12	3.12
851	2.68	2.64	2.59
852	2.91	2.87	2.88
853	4.03	4.06	4.02
854	4.25	4.23	4.3
855	6.93	6.98	6.92
856	9.62	9.6	9.62
857	9.84	9.78	9.84
858	7.61	7.6	7.61
859	5.59	5.59	5.62
860	7.83	7.82	7.84
861	6.93	6.98	6.92
862	3.8	3.83	3.83
863	4.25	4.23	4.3
864	4.47	4.54	4.48
865	4.7	4.65	4.71
866	5.37	5.39	5.41
867	5.82	5.81	5.82
868	3.8	3.83	3.83
869	3.58	3.59	3.53
870	6.93	6.98	6.92
871	8.05	8.06	8.13
872	9.17	9.2	9.18
873	9.84	9.78	9.84
874	10.51	10.52	10.51
875	9.62	9.6	9.62
876	7.83	7.82	7.84
877	6.26	6.28	6.28
878	4.7	4.65	4.71
879	3.13	3.12	3.12
880	4.7	4.65	4.71
881	7.38	7.37	7.32
882	10.07	10.08	9.96
883	6.49	6.47	6.46
884	10.74	0	0
885	9.4	9.42	9.44
886	5.82	5.81	5.82
887	5.59	5.59	5.62
888	5.37	5.39	5.41
889	5.37	5.39	5.41

890	5.14	5.12	5.17
891	4.92	4.94	4.94
892	10.29	10.26	10.24
893	10.74	0	0
894	9.4	9.42	9.44
895	10.51	10.52	10.51
896	10.96	0	0
897	9.17	9.2	9.18
898	7.83	7.82	7.84
899	4.25	4.23	4.3
900	4.7	4.65	4.71
901	4.7	4.65	4.71
902	4.7	4.65	4.71
903	4.7	4.65	4.71
904	4.7	4.65	4.71
905	4.92	4.94	4.94
906	5.37	5.39	5.41
907	5.59	5.59	5.62
908	5.82	5.81	5.82
909	5.82	5.81	5.82
910	3.36	3.4	3.41
911	3.36	3.4	3.41
912	2.46	2.41	2.47
913	3.36	3.4	3.41
914	5.37	5.39	5.41
915	3.36	3.4	3.41
916	3.8	3.83	3.83
917	3.36	3.4	3.41
918	3.36	3.4	3.41
919	3.36	3.4	3.41
920	2.46	2.41	2.47
921	3.36	3.4	3.41
922	4.92	4.94	4.94
923	6.26	6.28	6.28
924	7.83	7.82	7.84
925	3.8	3.83	3.83
926	4.92	4.94	4.94
927	5.82	5.81	5.82
928	6.26	6.28	6.28
929	6.49	6.47	6.46
930	3.36	3.4	3.41

931	3.36	3.4	3.41
932	3.36	3.4	3.41
933	3.36	3.4	3.41
934	3.36	3.4	3.41
935	3.36	3.4	3.41
936	3.36	3.4	3.41
937	3.36	3.4	3.41
938	8.05	8.06	8.13
939	9.17	9.2	9.18
940	10.29	10.26	10.24
941	4.7	4.65	4.71
942	8.95	9.07	8.95
943	9.17	9.2	9.18
944	7.61	7.6	7.61
945	5.82	5.81	5.82
946	5.82	5.81	5.82
947	5.82	5.81	5.82
948	6.93	6.98	6.92
949	6.93	6.98	6.92
950	6.49	6.47	6.46
951	6.04	6.11	6.06
952	5.82	5.81	5.82
953	5.82	5.81	5.82
954	9.84	9.78	9.84
955	10.74	0	0
956	6.93	6.98	6.92
957	6.26	6.28	6.28
958	4.7	4.65	4.71
959	4.47	4.54	4.48
960	4.47	4.54	4.48
961	4.25	4.23	4.3
962	4.03	4.06	4.02
963	4.7	4.65	4.71
964	5.37	5.39	5.41
965	6.26	6.28	6.28
966	6.93	6.98	6.92
967	6.93	6.98	6.92
968	8.05	8.06	8.13
969	9.17	9.2	9.18
970	10.29	10.26	10.24
971	10.96	0	0

972	10.29	10.26	10.24
973	7.61	7.6	7.61
974	5.14	5.12	5.17
975	2.46	2.41	2.47
976	4.7	4.65	4.71
977	4.7	4.65	4.71
978	4.7	4.65	4.71
979	4.25	4.23	4.3
980	3.8	3.83	3.83
981	3.36	3.4	3.41
982	6.49	6.47	6.46
983	4.92	4.94	4.94
984	3.13	3.12	3.12
985	6.26	6.28	6.28
986	6.71	6.75	6.72
987	7.38	7.37	7.32
988	6.49	6.47	6.46
989	3.58	3.59	3.53
990	3.13	3.12	3.12
991	6.93	6.98	6.92
992	10.07	10.08	9.96
993	6.93	6.98	6.92
994	6.71	6.75	6.72
995	6.49	6.47	6.46
996	6.49	6.47	6.46
997	6.26	6.28	6.28
998	6.04	6.11	6.06
999	5.82	5.81	5.82
1000	5.82	5.81	5.82
1001	3.36	3.4	3.41
1002	5.82	5.81	5.82
1003	4.7	4.65	4.71
1004	10.29	10.26	10.24
1005	6.93	6.98	6.92
1006	4.7	4.65	4.71
1007	6.93	6.98	6.92
1008	4.7	4.65	4.71
1009	3.36	3.4	3.41
1010	4.7	4.65	4.71
1011	3.36	3.4	3.41
1012	3.36	3.4	3.41

1013	3.36	3.4	3.41
1014	5.82	5.81	5.82
1015	4.7	4.65	4.71
1016	4.7	4.65	4.71
1017	3.36	3.4	3.41
1018	3.36	3.4	3.41
1019	4.7	4.65	4.71
1020	3.36	3.4	3.41
1021	3.36	3.4	3.41
1022	5.82	5.81	5.82
1023	3.36	3.4	3.41
1024	10.29	10.26	10.24
1025	5.82	5.81	5.82
1026	3.36	3.4	3.41
1027	4.7	4.65	4.71
1028	9.17	9.2	9.18
1029	5.82	5.81	5.82
1030	4.7	4.65	4.71
1031	4.7	4.65	4.71
1032	3.36	3.4	3.41
1033	4.7	4.65	4.71
1034	4.7	4.65	4.71
1035	3.36	3.4	3.41
1036	3.36	3.4	3.41
1037	4.7	4.65	4.71
1038	4.7	4.65	4.71
1039	6.93	6.98	6.92
1040	5.82	5.81	5.82
1041	3.36	3.4	3.41
1042	5.82	5.81	5.82
1043	5.82	5.81	5.82
1044	3.36	3.4	3.41
1045	4.7	4.65	4.71
1046	5.82	5.81	5.82
1047	6.93	6.98	6.92
1048	3.36	3.4	3.41
1049	4.7	4.65	4.71
1050	4.7	4.65	4.71
1051	3.36	3.4	3.41
1052	8.05	8.06	8.13
1053	4.7	4.65	4.71

1054	4.7	4.65	4.71
1055	8.05	8.06	8.13
1056	5.82	5.81	5.82
1057	4.7	4.65	4.71
1058	6.93	6.98	6.92
1059	5.82	5.81	5.82
1060	3.36	3.4	3.41
1061	3.36	3.4	3.41
1062	5.82	5.81	5.82
1063	8.05	8.06	8.13
1064	6.93	6.98	6.92
1065	3.58	3.59	3.53
1066	10.29	10.26	10.24
1067	5.82	5.81	5.82
1068	6.93	6.98	6.92
1069	5.82	5.81	5.82
1070	10.29	10.26	10.24
1071	10.29	10.26	10.24
1072	10.29	10.26	10.24
1073	10.29	10.26	10.24
1074	9.17	9.2	9.18
1075	10.29	10.26	10.24
1076	8.05	8.06	8.13
1077	10.29	10.26	10.24
1078	6.93	6.98	6.92
1079	6.93	6.98	6.92
1080	4.7	4.65	4.71
1081	9.17	9.2	9.18
1082	6.93	6.98	6.92
1083	6.93	6.98	6.92
1084	9.17	9.2	9.18
1085	4.7	4.65	4.71
1086	6.93	6.98	6.92
1087	9.17	9.2	9.18
1088	5.82	5.81	5.82
1089	5.82	5.81	5.82
1090	4.7	4.65	4.71
1091	5.82	5.81	5.82
1092	5.82	5.81	5.82
1093	3.36	3.4	3.41
1094	9.17	9.2	9.18

1095	6.93	6.98	6.92
1096	5.82	5.81	5.82
1097	10.29	10.26	10.24
1098	9.17	9.2	9.18
1099	5.82	5.81	5.82
1100	4.7	4.65	4.71
1101	4.7	4.65	4.71
1102	4.7	4.65	4.71
1103	10.29	10.26	10.24
1104	10.29	10.26	10.24
1105	10.29	10.26	10.24
1106	8.95	9.07	8.95
1107	7.61	7.6	7.61
1108	6.04	6.11	6.06
1109	4.7	4.65	4.71
1110	4.7	4.65	4.71
1111	3.36	3.4	3.41
1112	6.93	6.98	6.92
1113	5.82	5.81	5.82
1114	3.36	3.4	3.41
1115	6.93	6.98	6.92
1116	4.7	4.65	4.71
1117	3.36	3.4	3.41
1118	4.7	4.65	4.71
1119	6.93	6.98	6.92
1120	4.7	4.65	4.71
1121	5.82	5.81	5.82
1122	3.36	3.4	3.41
1123	5.82	5.81	5.82
1124	4.7	4.65	4.71
1125	5.82	5.81	5.82
1126	8.05	8.06	8.13
1127	4.7	4.65	4.71
1128	6.93	6.98	6.92
1129	4.7	4.65	4.71
1130	6.49	6.47	6.46
1131	8.5	8.53	8.48
1132	10.29	10.26	10.24
1133	8.05	8.06	8.13
1134	6.93	6.98	6.92
1135	4.7	4.65	4.71

1136	3.36	3.4	3.41
1137	4.7	4.65	4.71
1138	6.93	6.98	6.92
1139	6.93	6.98	6.92
1140	9.17	9.2	9.18
1141	8.05	8.06	8.13
1142	5.82	5.81	5.82
1143	3.36	3.4	3.41
1144	4.7	4.65	4.71
1145	6.93	6.98	6.92
1146	6.93	6.98	6.92
1147	6.93	6.98	6.92
1148	6.93	6.98	6.92
1149	6.93	6.98	6.92
1150	9.17	9.2	9.18
1151	10.29	10.26	10.24
1152	8.05	8.06	8.13
1153	10.29	10.26	10.24
1154	5.82	5.81	5.82
1155	6.93	6.98	6.92
1156	8.05	8.06	8.13
1157	10.29	10.26	10.24
1158	8.05	8.06	8.13
1159	6.93	6.98	6.92
1160	9.17	9.2	9.18
1161	8.05	8.06	8.13
1162	6.93	6.98	6.92
1163	4.7	4.65	4.71
1164	6.93	6.98	6.92
1165	4.7	4.65	4.71
1166	3.36	3.4	3.41
1167	3.36	3.4	3.41
1168	3.36	3.4	3.41
1169	3.36	3.4	3.41
1170	3.36	3.4	3.41
1171	3.36	3.4	3.41
1172	5.82	5.81	5.82
1173	8.05	8.06	8.13
1174	9.17	9.2	9.18
1175	4.7	4.65	4.71
1176	3.36	3.4	3.41

1177	3.36	3.4	3.41
1178	4.7	4.65	4.71
1179	5.82	5.81	5.82
1180	4.7	4.65	4.71
1181	4.7	4.65	4.71
1182	5.82	5.81	5.82
1183	4.7	4.65	4.71
1184	3.36	3.4	3.41
1185	5.82	5.81	5.82
1186	8.05	8.06	8.13
1187	3.36	3.4	3.41
1188	8.05	8.06	8.13
1189	9.17	9.2	9.18
1190	3.36	3.4	3.41
1191	6.93	6.98	6.92
1192	9.17	9.2	9.18
1193	9.17	9.2	9.18
1194	10.29	10.26	10.24
1195	8.05	8.06	8.13
1196	9.17	9.2	9.18
1197	9.17	9.2	9.18
1198	8.05	8.06	8.13
1199	10.29	10.26	10.24
1200	10.29	10.26	10.24
1201	8.05	8.06	8.13
1202	9.17	9.2	9.18
1203	10.29	10.26	10.24
1204	8.05	8.06	8.13
1205	6.93	6.98	6.92
1206	6.93	6.98	6.92
1207	3.36	3.4	3.41
1208	6.93	6.98	6.92
1209	9.17	9.2	9.18
1210	8.05	8.06	8.13
1211	4.7	4.65	4.71
1212	3.36	3.4	3.41
1213	4.7	4.65	4.71
1214	5.82	5.81	5.82
1215	8.05	8.06	8.13
1216	4.7	4.65	4.71
1217	3.36	3.4	3.41

1218	3.36	3.4	3.41
1219	6.93	6.98	6.92
1220	3.36	3.4	3.41
1221	5.82	5.81	5.82
1222	8.05	8.06	8.13
1223	6.93	6.98	6.92
1224	5.82	5.81	5.82
1225	4.7	4.65	4.71
1226	3.36	3.4	3.41
1227	3.36	3.4	3.41
1228	3.36	3.4	3.41
1229	4.7	4.65	4.71
1230	3.36	3.4	3.41
1231	3.36	3.4	3.41
1232	3.36	3.4	3.41
1233	5.82	5.81	5.82
1234	6.93	6.98	6.92
1235	4.7	4.65	4.71
1236	3.36	3.4	3.41
1237	3.36	3.4	3.41
1238	4.7	4.65	4.71
1239	9.84	9.78	9.84
1240	10.29	10.26	10.24
1241	10.29	10.26	10.24
1242	9.17	9.2	9.18
1243	8.05	8.06	8.13
1244	4.7	4.65	4.71
1245	3.36	3.4	3.41
1246	3.36	3.4	3.41
1247	4.7	4.65	4.71
1248	3.36	3.4	3.41
1249	8.05	8.06	8.13
1250	6.93	6.98	6.92
1251	3.36	3.4	3.41
1252	4.7	4.65	4.71