

Asia Pacific Research Initiative for Sustainable Energy Systems 2013 (APRISES13)

**Office of Naval Research
Grant Award Number N00014-14-1-0054**

CEILING FAN STUDY: GAP ANALYSIS

Task 7

Prepared For
Hawaii Natural Energy Institute

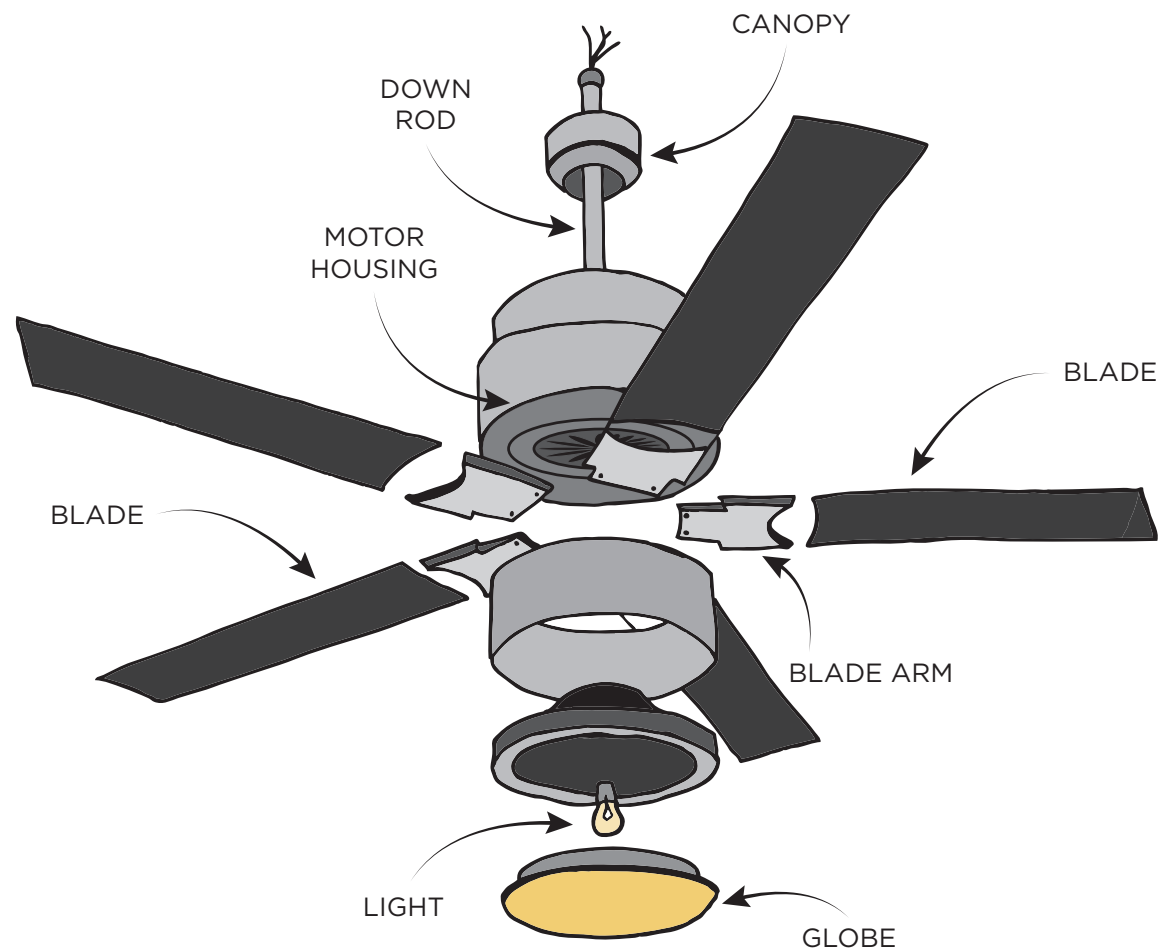
Prepared By
MKThink

January 2018



HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa





DELIVERABLE 4: FINAL GAP ANALYSIS

CONTRACT NO. Z10152521
JANUARY 2018



HNEI

Hawai'i Natural Energy Institute

School of Ocean and Earth Science and Technology
University of Hawai'i at Mānoa

THiNK^{MK}

**HNEI CONTRACT
NO. Z10152521**

**University of Hawaii's
Asia-Pacific Research
Initiative for Sustainable
Energy Systems (APRISES)**

Task 7 - Energy Efficiency

**This project is supported
and funded by the Office
of Naval Research in grant
awards: N00014-12-1-1496
and N00014-14-1-0054.**

Prepared for:

Hawaii Natural Energy Institute
University of Hawaii at Manoa

Contact: James Maskrey, MEP, MBA
Project Manager
maskrey2@hawaii.edu
(808) 956-3645
1680 East West Road, Suite 109
Honolulu, HI 96822

Prepared by MKThink

Principal in Charge: Mark R. Miller, FAIA LEEDAP
Research Team Lead: Signo Uddenberg
Research Team: Amy Nagengast PhD PE, Mayssen
Labidi
Partners: Roundhouse One

Contact: Signo Uddenberg, EIT LEEDAP
uddenberg@mkthink.com
(415) 288-3389
1500 Sansome Street
San Francisco, CA. 94111

Table of Contents

1

Introduction

Study Context.....	2
Gap Organizational Framework.....	3
Number of Gaps by Category	4
Prioritization Method.....	5

2

Gap Analysis

Glossary	9
Gap Summary List.....	10
Detailed Gap List.....	18

1

Introduction

Study Context	2
Gap Organizational Framework	3
Number of Gaps by Category	4
Gap Prioritization Methodology	5

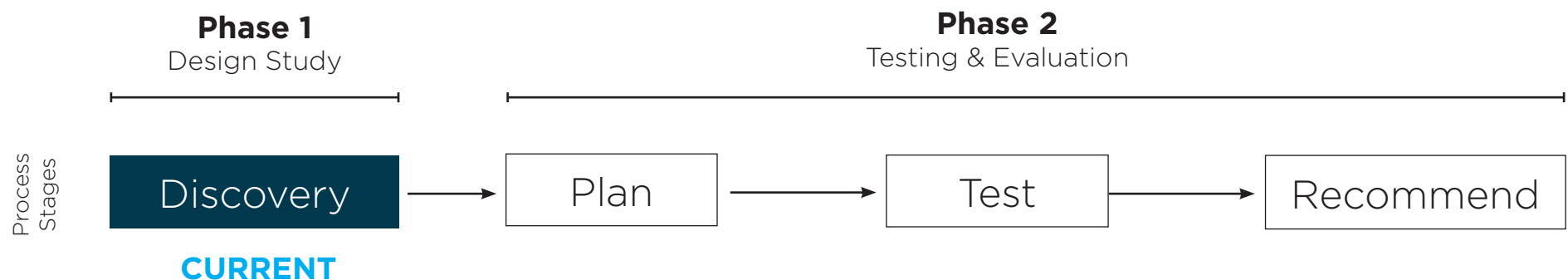
Tropical areas, such as Hawaii, are looking for innovative ways to improve *thermal comfort*. While ceiling fans are not new, the lack of research in some areas and the advances in technology in others, make it difficult for designers and practitioners to make optimal fan selection decisions supported by data (research) and appropriate for different contexts. In support of the University of Hawaii's "Asia Pacific Research Initiative for Sustainable Energy Systems (APRISES)" Task 7 Energy Efficiency, this initiative aims to advance the knowledge and application of ceiling fan technology in various environments and cultures. A ceiling fan for this research is defined as a non-portable device that is suspended from a ceiling for circulating air via the rotation of fan blades.

This ceiling fan initiative is organized into two phases. **Phase 1 (Design Study)** focuses on acquiring and summarizing ceiling fan knowledge from academic and industry sources while also identifying gaps for further study. **Phase 2 (Testing and Evaluation)** defines research study(ies) from the Phase 1 Gap Analysis to plan and execute at a selected site in Hawaii.

The objectives of Phase 1 are below.

- Define typologies of ceiling fan applications and a portfolio of existing and emerging fan technologies
- Develop new or leverage existing metrics to evaluate the performance of the portfolio of fan technologies
- Conduct literature survey of current CFD simulation techniques and their applicability to quantifying performance of selected fan typologies.

This report will cover the gaps in research identified earlier in Phase 1 and documented in the *Ceiling Fan Primer* report.



Gap Organizational Framework

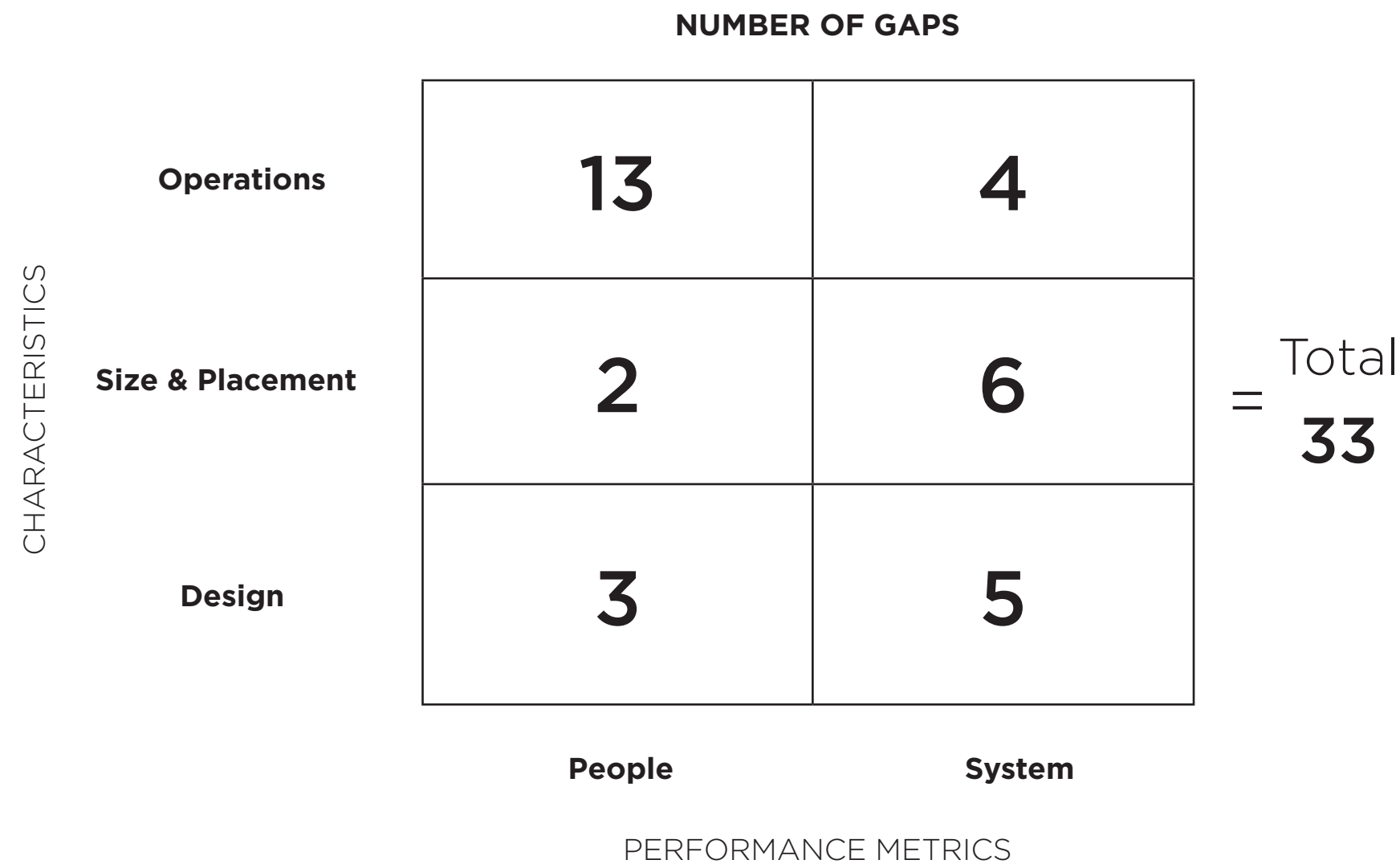
A total of 33 gaps in ceiling fan knowledge were recorded during the research for the *Ceiling Fan Primer*. The gaps included information that was not available for any type of ceiling fan technology or application as well as information that was not available for a subset of a technology, application or performance metric.

The gaps are organized using a 3x2 matrix to separate the characteristics of the ceiling fan systems from the performance metrics used to evaluate the system. The rows represent the characteristic categories as used in the *Ceiling Fan Primer*: Operations, Size & Placement, and Design. The columns represent the two performance metrics categories: People (effectiveness) and System (efficiency). The report both organizes and prioritizes the gaps using this matrix.

CHARACTERISTICS		GAP CATEGORIES	
	Operations (O)	How do Operations impact People performance? (O-P)	How do Operations impact System performance? (O-S)
	Size & Placement (S)	How does Size & Placement impact People performance? (S-P)	How does Size & Place- ment impact System perfor- mance? (S-S)
	Design (D)	How does Design impact People performance? (D-P)	How does Design impact System performance? (D-S)
		People (P)	System (S)
PERFORMANCE METRICS			

Number of Gaps by Category

The below chart summarizes the 33 gaps using the categorization framework previously described.



Gap Prioritization Methodology

The gaps are prioritized using the following criteria:

1. Practitioner & User Focused - Prioritize studies that **leverage existing technologies** (i.e. focus on improving Operations and Size/Placement because they can be immediately implemented). To assign priorities to the categories in the below matrix, points are first distributed from 1-3 by row. Points are allocated in the following way: 3 points: Operations, 2 points: Size & Placement, 1 point: Design.
2. Focus on **People** (Effectiveness) before **System** (Efficiency) - Prioritize studies that link Design, Size/Place, Operations to effectiveness (thermal comfort, etc.) before efficiency (CFM/W, etc.) To assign priorities to the categories in the below matrix, points are then distributed from 1-2 by column. Points are allocated in the following way: 2 points: People, 1 point: System.

Each category was assigned points based on the above criteria and then ranked from the lowest number of points to the highest to form the prioritization schedule. Gap categories that ended up in a tie were prioritized by those in People and Operations/Size-Placement, for the reasons stated in the prioritization criteria.

PRIORITIZATION SCHEDULE (1 = High, 6 = Low)		
Operations	1	4
	2	5
	3	6
Size & Placement	People	System

2

Gap Analysis

Glossary	9
Gap Summary List	10
Detailed Gap List	18

This page is left intentionally blank.

Alliesthesia

Alliesthesia is the pleasant or unpleasant sensation that results from a new stimulus and is directly influenced by an individual's internal state. The aim of using variable stimulus such as air flow to induce alliesthesia is to reduce sensory adaptation that could nullify positive sensations. For instance, the use of variable air flow ensures that occupants do not adapt to a steady state but rather that the body is restored to what is a perceived pleasurable state.

ASHRAE

The American Society of Heating Refrigerating and Air-Conditioning Engineers is an association that regulates the design and construction of indoor heating, ventilation, air-conditioning and refrigeration systems.

CFD Modeling

Computational Fluid Dynamics (CFD) is a modeling technique that helps predict fluid flow, such as airflow phenomena and thermal distribution by using mathematical modeling, numerical methods and software tools.

CFM

Cubic feet per minute (CFM) is a measurement of the amount of air flow produced by a ceiling fan per minute.

CFM/W

Cubic feet per minute per watt is a unit of efficacy that measures the amount of air flow produced by a ceiling fan per minute per unit of energy (Watt).

HVLS Fans

High-Volume Low-Speed (HVLS) fans are fans with airfoil blades and diameters greater than 7 feet (84") that operate at low speeds and distribute large volumes of air. These fans are typically used in large commercial or industrial facilities that require significant airflow over large areas.

Strobe Effect

A strobe effect is when light perpetually brightens and dims as it penetrates and passes through a moving ceiling fan, causing dizziness and confusion for occupants.

Gap Summary List: **Operations - People (Priority 1)**

2 - Gap Analysis

The following gaps relate to the **operations** of ceiling fans and how those decisions impact **people** (effectiveness). Gaps in this category were ranked as Priority 1.

Ref	Gap & Research Question	Page
1.1	Fan Speeds How does thermal comfort change with different fan speeds settings?	18
1.2	Fan/Ventilation Interactions How do ceiling fans impact thermal comfort when used in buildings with natural, mixed-mode & HVAC ventilation systems?	18
1.3	Cognitive Abilities How does the use of ceiling fans impact cognitive abilities, learning ability and productivity in different settings?	19
1.4	Behavior Impacts How is occupant behavior impacted by the use of ceiling fans?	19
1.5	Fan Type/Size How is thermal comfort impacted by fan type, size and quantity?	20
1.6	Controls How do usage patterns and user preferences vary across the different control technologies?	20
1.7	Multi-Fan Controls How do user patterns change across the different multi-fan control devices?	21

Gap Summary List: **Operations - People (Priority 1)**

2 - Gap Analysis

The following gaps relate to the **operations** of ceiling fans and how those decisions impact **people** (effectiveness). Gaps in this category were ranked as Priority 1.

Ref	Gap & Research Question	Page
1.8	Fan Use How do usage patterns and preferences of ceiling fans differ by age?	21
1.9	School Codes & Standards Can installation and operational codes and standards be developed for fan use in educational settings? What would these codes and standards look like?	22
1.10	Intermittent Speeds How does modulating fan speed settings contribute to occupant comfort?	22
1.11	Personal Control How is thermal comfort impacted by the different control technologies?	23
1.12	Lighting Obstructions How does dimming the lights to reduce the strobe effect or maintaining the strobe effect impact occupants? What level of strobe is acceptable for human comfort?	23
1.13	Fan Comparisons How do ceiling fans compare with other fan alternatives on thermal comfort (i.e. desk fans, standing fans)?	24

Gap Summary List: **Size/Place - People (Priority 2)**

The following gaps relate to the **sizing and placement** of ceiling fans and how those decisions impact **people** (effectiveness). Gaps in this category were ranked as Priority 2.

Ref	Gap & Research Question	Page
2.1	Alliesthesia How might the placement of fans with variable speed modes create positive alliesthesia?	25
2.2	Air Movement with 2+ Fans How do air movement profiles change with multiple ceiling fans (more than 2)?	25

Gap Summary List: **Design - People (Priority 3)**

2 - Gap Analysis

The following gaps relate to the **design** of ceiling fans and how those design decisions impact **people** (effectiveness). Gaps in this category were ranked as Priority 3.

Ref	Gap & Research Question	Page
3.1	Alliesthesia How might the design of fans with variable fan speeds create positive alliesthesia?	26
3.2	Blade Quantity & Pitch How does blade quantity, size, width and pitch impact thermal comfort in commercial and industrial applications?	26
3.3	Multi-Fan Controls What are typical and proposed usage patterns with multi-fan controls? What design changes can impact usage patterns?	27

Gap Summary List: **Operations - System (Priority 4)**

2 - Gap Analysis

The following gaps relate to the **operations** of ceiling fan systems and how those decisions impact **system** metrics (efficiency). Gaps in this category were ranked as Priority 4.

Ref	Gap & Research Question	Page
4.1	CFD Modeling What is the accuracy of (e.g. +/- 20%) CFD at predicting air velocity and temperature distribution in a room?	28
4.2	Fan Use When and how do occupants use ceiling fans in different room types in different applications (i.e. schools, offices)?	28
4.3	Fan/Ventilation Use How are ceiling fans used when other ventilation systems are in use?	29
4.4	Fan/Ventilation Interactions How does the use ceiling fans impact air movement when used in buildings with natural, mixed-mode & HVAC ventilation systems?	29

Gap Summary List: **Size/Place - System (Priority 5)**

2 - Gap Analysis

The following gaps relate to the **sizing and placement** of ceiling fan systems and how those decisions impact **system** metrics (efficiency). Gaps in this category were ranked as Priority 5.

Ref	Gap & Research Question	Page
5.1	Multiple Fan Placement What are placement guidelines of multiple flat and airfoil blade ceiling fans for different room sizes and configurations?	30
5.2	Sizing & Placement Guidelines What are sizing and placement guidelines for classrooms, cafeterias, and other school room types?	30
5.3	Strobe Effect How can spatial orientation guidelines help minimize the strobe effect for all fan types? How might distance change by light source (i.e. fluorescent, LED) and light display type (i.e. panel, hanging light recessed lighting)?	31
5.4	Irregular Placement How do placement guidelines for single and multiple ceiling fans change with irregular room and ceiling configurations where the fans cannot be placed equidistantly apart?	31
5.5	Multiple Fan Air Movement What is the effect of occupants in a space on the air movement of multiple ceiling fans and how are pressure zones affected?	32
5.6	Air Profiles by Application How do air movement and speed profiles vary for different room types in residential, commercial and industrial settings?	32

Gap Summary List: **Design - System (Priority 6)**

The following gaps relate to the **design** of ceiling fan systems and how those design decisions impact **system** metrics (efficiency). Gaps in this category were ranked as Priority 6.

Ref	Gap & Research Question	Page
6.1	Air Speed Profiles How do average air speed profiles change by fan type, blade type (i.e. flat, foil, HVLS), by size, and by manufacturer?	33
6.2	Blade Quantity & Pitch How does blade quantity, size, width and pitch impact system performance in commercial and industrial applications?	33
6.3	Standardized Air Movement & Speed Profiles How do flat and airfoil blade shapes impact standardized air movement and speed profiles?	34
6.4	Area of Influence How does furniture or other obstructions affect ceiling fan areas of influence?	34
6.5	Retrofit Opportunities How can existing fans be retrofitted to increase air flow efficiency (CFM/W)?	35

This page is left intentionally blank.

1.1 FAN SPEEDS

Priority: **1**

Gap Description: Thermal comfort ratings are directly impacted by fan speed. Previously conducted research assessed how different speeds impact thermal comfort; however, not all speeds were tested in different temperature and humidity conditions, limiting the understanding of thermal comfort. Additional research could be done to understand how different fan speeds impact comfort levels to ensure that fan speeds are properly set.

Research Question: How does thermal comfort change with different fan speeds settings?

Primer Location: Operations: pg. 54-66

1.2 FAN/VENTILATION INTERACTIONS

Priority: **1**

Gap Description: Ceiling fans are often used with other ventilation systems, impacting air flow and occupant thermal comfort levels. Thermal comfort levels are directly influenced by air speed and fluctuations in air movement and speed caused by fan and ventilation system use will have implications on comfort levels. This impact is not well understood, and additional research could inform recommendations on fan speed settings to maximize occupant thermal comfort.

Research Question: How do ceiling fans impact thermal comfort when used in buildings with natural, mixed-mode & HVAC ventilation systems?

Primer Location: Air Movement: pg. 63

1.3 COGNITIVE ABILITIES

Priority: **1**

Gap Description: There is a positive association between indoor air quality and cognitive performance. Ceiling fans improve air movement and occupant comfort, potentially impacting the cognitive performance and productivity levels of occupants. Researching the impact of ceiling fan use on cognitive performance and productivity could prompt further use of ceiling fans to optimize human performance in settings where heightened cognitive skills are valued (i.e. schools and offices).

Research Question: How does the use of ceiling fans impact cognitive abilities, learning ability and productivity in different settings?

Primer Location: Air Movement: pg. 63

1.4 BEHAVIOR IMPACTS

Priority: **1**

Gap Description: Introducing a ceiling fan into a room may alter occupant behavior. Insight into how occupants adapt to ceiling fans could alter operational decisions, reducing unnecessary distraction or discomfort burdens. Additional research is needed to understand occupant behavior with fan use, which could inform operational strategies, such as altering speed settings and leveraging intermittent modes. For instance, if an occupant adjusts their desk orientation to avoid a ceiling fan's air, an operational strategy or mode of lower and more variable fan speeds could be introduced.

Research Question: How is occupant behavior impacted by the use of ceiling fans?

Primer Location: Air Movement: pg. 63

1.5 FAN TYPE/SIZE

Priority: **1**

Gap Description: Air speed profiles change by fan type (i.e. standard, hugger, HVLS), size or fan diameter, and quantity in a room. Thermal comfort has yet to be studied for different fan types, sizes and quantities. Additional research could inform which fan type, size and quantity should be used to meet specific cooling effects or comfort goals.

Research Question: How is thermal comfort impacted by fan type, size and quantity?

Primer Location: Design: pg. 16-34

1.6 CONTROLS

Priority: **1**

Gap Description: There are five types of ceiling fan controls and each has different operational modes, such as multi-speed, variable or intermittent speed. Existing research on fan controls focuses on improving the devices' capabilities; however, usage patterns and preferences of each control technology could be studied more in-depth. Additional research could inform the selection and operation of control technologies based on specific use types and user preferences.

Research Question: How do usage patterns and user preferences vary across the different control technologies?

Primer Location: Operations: pg. 54-66:

1.7 MULTI-FAN CONTROLS

Priority: **1**

Gap Description: There are several control devices available that allow multiple ceiling fans to be controlled by a single device. To date, manufacturers have primarily focused their efforts on enhancing the capabilities and operational 'modes' of these devices. Additional research could investigate usability, user patterns and preferences to better understand how and which control features are used. The results of this research could inform an ease of use scaling system that recommends the selection and operation of multi-fan control devices based on specific user characteristics and usage patterns.

Research Question: How do user patterns change across the different multi-fan control devices?

Primer Location: Operations: pg. 54-66

1.8 FAN USE

Priority: **1**

Gap Description: Use of ceiling fans may differ across age groups due to differences in physiology, internal body temperature states and sensitivity to temperature and wind, affecting individuals' responses to air movement. Additional research could be conducted to better understand preferences across demographics. This research could inform fan selection and operation in various settings, such as schools or offices, to cater to the unique cooling needs of individuals.

Research Question: How do usage patterns and preferences of ceiling fans differ by age?

Primer Location: Flat Blade Air Movement, Foil Blade Air Movement: pg. 24-25, 29

1.9 SCHOOL CODES & STANDARDS

Priority: **1**

Gap Description: Ventilation codes and standards, such as from ASHRAE, regulate acceptable environmental conditions in indoor environments and evaluate thermal comfort. Thermal comfort evaluation, which includes the measurement of several variables such as air speed, temperature, among others may vary across settings (i.e. commercial, school) and building layout. Currently there are no codes or standards on ceiling fan use in educational settings. Additional research could help to inform the development of codes and standards for standardizing the installation and operation of ceiling fans in educational settings.

Research Question: Can installation and operational codes and standards be developed for fan use in educational settings? What would these codes and standards look like?

Primer Location: Operations: pg. 54-66

1.10 INTERMITTENT SPEEDS

Priority: **1**

Gap Description: Intermittent and variable fan speeds may contribute to alliesthesia, the thermal sensations that occur when exposed to variable stimuli such as wind and air movement. Additional research could help to understand the impact of fan speed variability on thermal comfort, which would in turn inform use of fans and fan speeds.

Research Question: How do modulating fan speed settings contribute to occupant comfort?

Primer Location: Air Movement: pg. 63

1.11 PERSONAL CONTROL

Priority: **1**

Gap Description: There is a positive association between perception of control in an environment and comfort. This research has yet to extend to ceiling fans and fan controls. Understanding how the level of personal control of operational settings impacts occupant comfort could alter how and which control devices are used.

Research Question: How is thermal comfort impacted by the different control technologies?

Primer Location: Operations: pg. 54-66

1.12 LIGHTING OBSTRUCTIONS

Priority: **1**

Gap Description: The strobe effect is a perpetual shadow flicker that occurs when ceiling fans are placed below lighting fixtures. When this effect is detected, decisions need to be made to reduce it by either changing fan speeds, minimizing light, or repositioning the fan or light. General placement guidelines exist that address the strobe effect caused by poor fan placement; however, it would be useful to know the level of strobe that is acceptable for human comfort so that equipment displacements or replacements are minimized. Additionally, knowing the trade-off between the strobe effect and dimming lights would inform how fans and lights are to be operated when a strobe effect is detected.

Research Question: What are the mitigating actions to reduce the strobe effect or to maintain the strobe effect with minimal occupants? What level is acceptable for human comfort?

Primer Location: Lighting Obstructions: pg. 51

1.13 FAN COMPARISONS

Priority: **1**

Gap Description: Ceiling fans provide overhead air movement to improve thermal conditions in a space. Other types of fans provide lateral air movement with different configurations relative to a user, leading to differing areas of influence that may also impact perceived comfort levels. The existing research into the directional impact of different fan types and configurations is limited.

Research Question: How do ceiling fans compare with other fan alternatives on thermal comfort (i.e. desk fans, standing fans)?

Primer Location: Operations: pg. 54-66

2.1 ALLIESTHESIA

Priority: **2**

Gap Description: Alliesthesia is the pleasant or unpleasant sensation caused by sensory stimulus and influenced by an individual's internal state. The individual's physiology as well as the stimulus' characteristics influence whether alliesthesia is considered positive or negative. An example of positive alliesthesia is a cold breeze on a hot day that restores the body's more neutral temperature. Additionally, these pleasant sensations can arise from differences in temperature and air flow across the skin's surface. The placement of fans generating variable air movement could create a positive sensory stimulation, which could increase internal comfort or satisfaction. Additional research could help to determine the placement needed to achieve positive alliesthesia.

Research Question: How might the placement of fans with variable speed modes create positive alliesthesia?

Primer Location: Designing for Alliesthesia: pg. 67

2.2 AIR MOVEMENT WITH 2+ FANS

Priority: **2**

Gap Description: Air flow patterns are used to inform fan placement and ensure effective air distribution within a space. The air flow patterns for two ceiling fans are available in industry documentation; however, no air flow patterns were found for more than two fans. Multiple fans are often required in large commercial spaces, such as schools, offices or industrial facilities, and further research could inform multiple fan placement in commercial settings.

Research Question: How do air movement profiles change with multiple ceiling fans (more than two)?

Primer Location: Flat Blade Fan Air Movement Profile; Airfoil Blade HVLS Fan Air Movement Profile: pg. 24, 27

3.1 ALLIESTHESIA

Priority: **3**

Gap Description: Alliesthesia is the pleasant or unpleasant sensation caused by sensory stimulus and influenced by an individual's initial temperature state. Alliesthesia can arise from differences in temperature and air flow across the skin's surface. As stated previously in Gap #2.1, the placement of fans generating variable air flow can include either positive or negative alliesthesia. Similarly, the design of fans (i.e. blade type, quantity or pitch) generating variable air flow may affect the sensations and comfort of occupants. Additional research could be done to determine the specific designs needed to achieve positive alliesthesia.

Research Question: How might the design of fans with variable fan speeds create positive alliesthesia?

Primer Location: Designing for Alliesthesia: pg. 67

3.2 BLADE QUANTITY & PITCH

Priority: **3**

Gap Description: Blade quantity, width and pitch affect ceiling fans' ability to move and redirect air downward. Fans with four blades and a blade pitch of 8-10 or 12-15 degrees optimize air movement and efficiency in most settings. However, it is unknown what specific fan characteristics such as blade size or pitch affect the thermal comfort levels of occupants, especially in commercial and industrial settings. Understanding occupants' comfort levels based on specific fan characteristics may alter manufacturer's design of ceiling fan and fan blades (i.e. quantity, width and pitch) to optimize for occupant comfort.

Research Question: How does blade quantity, size, width and pitch impact thermal comfort in commercial and industrial applications?

Primer Location: Blade Shape, Quantity, Pitch: pg. 18

3.3 MULTI-FAN CONTROLS

Priority: **3**

Gap Description: Multiple ceiling fans can be controlled by several control devices available on the market. There is a need to assess user patterns and preferences when using multiple fan control devices. While understanding how and which current device features are used could inform operational decisions, as described in Gap #1.7 Multi-Fan Controls, this information could also lead to changes in design and these changes could help users achieve maximum performance of multiple fans.

Research Question: What are typical and proposed usage patterns with multi-fan controls? What design changes can impact usage patterns?

Primer Location: Operations: pg. 54-66

4.1 CFD MODELING

Priority: **4**

Gap Description: CFD Modeling predicts air flow patterns and allows practitioners to evaluate air velocity and temperature distributions when ceiling fans are in use. There are no existing best practice guidelines or standard methods for verification of CFD models, and few case studies comparing actual and predicted air velocity and temperature distribution. Determining the accuracy level of predicting air velocity and temperature distribution could help inform ceiling fan and furniture placement.

Research Question: What is the accuracy of (e.g. +/- 20%) CFD at predicting air velocity and temperature distribution in a room?

Primer Location: Modeling: pg. 31-33

4.2 FAN USE

Priority: **4**

Gap Description: Fan usage patterns inform the use of ceiling fans to optimize air movement and system performance. While one research study assesses fan usage patterns in households, information is limited on usage patterns in different commercial, educational and industrial applications and room types. Further research could improve the understanding of why fans are not used to their full capacity, which could inform educational and/or operational strategies.

Research Question: When and how do occupants use ceiling fans in different room types in different applications (i.e. schools, offices)?

Primer Location: Operations: pg. 54-66

4.3 FAN/VENTILATION USE

Priority: **4**

Gap Description: Ceiling fans are often installed in buildings with existing ventilation systems, which affects how fans are operated. Research on the use of ceiling fans in conjunction with other ventilation systems primarily focus on energy savings potential. Further research is necessary to assess various ventilation systems and how these impact fan air movement and speed. In better understanding which fan features (i.e. speed, operational modes) are well utilized and which are under-utilized when other ventilation systems are used, operational strategies could be developed to ensure that certain comfort objectives are met.

Research Question: How are ceiling fans used when other ventilation systems are in use?

Primer Location: Operations: pg. 54-66

4.4 FAN/VENTILATION INTERACTIONS

Priority: **4**

Gap Description: Ceiling fans are often used in conjunction with other ventilation systems, impacting air flow patterns and area of influence. The impact of fan and ventilation system interactions on air movement and speed are not well understood and further research is needed to understand interactions on air movement for various fan and ventilation system combinations. This information could inform recommendations on fan settings (i.e. speed, intermittency) to use with each ventilation system to maximize cooling potential.

Research Question: How does the use ceiling fans impact air movement when used in buildings with natural, mixed-mode & HVAC ventilation systems?

Primer Location: Air Movement: pg. 63

5.1 MULTIPLE FAN PLACEMENT

Priority: **5**

Gap Description: Multiple fans are often used in commercial and industrial applications to distribute large volumes of air. While it is generally recommended to place fans equidistant from all vertical walls, no standardized placement guidelines exist. To fill this gap, standardized placement guidelines that account for blade type, room characteristics and multiple fan air interactions are needed. These guidelines could allow users and practitioners to effectively place multiple ceiling fans to optimize air flow (CFM).

Research Question: What are placement guidelines of multiple flat and airfoil blade ceiling fans for different room sizes and configurations?

Primer Location: Flat Blade Sizing & Placement: pg. 41

5.2 SIZING & PLACEMENT GUIDELINES

Priority: **5**

Gap Description: Air movement is impacted by fan characteristics, room and building layout and nearby obstructions. In classrooms, cafeterias and laboratories, furniture and equipment impede air flow and impact the fan's intended performance. There are general guidelines for fan placement; however, these guidelines do not vary by application or room type. Additional research on fan air movement in different education space types could improve fan placement in schools to ensure optimal fan performance.

Research Question: What are sizing and placement guidelines for classrooms, cafeterias, and other school room types?

Primer Location: Sizing & Placement: pg. 38-49

5.3 STROBE EFFECT

Priority: **5**

Gap Description: The strobe effect is a perpetual shadow flicker that occurs when ceiling fans are placed below lighting fixtures. This effect is known to cause discomfort and trigger seizures in epileptics. While general placement recommendations exist for HVLS fans, none exist for other types of ceiling fans, lighting sources (i.e. fluorescent, LED), and light displays (i.e. panels, hanging light, recessed light). The study of the relationships between fans and light sources could improve the placement of fans to minimize the strobe effect.

Research Question: How can spatial orientation guidelines help minimize the strobe effect for all fan types? How might distance change by light source (i.e. fluorescent, LED) and light display type (i.e. panel, hanging light recessed lighting)?

Primer Location: Flat Blade Obstruction Guidelines; Foil Blade Obstruction Guidelines: pg. 41, 50

5.4 IRREGULAR PLACEMENT

Priority: **5**

Gap Description: Ceiling designs are evolving beyond standard flat or slanted shapes, altering proper fan placement. Placement guidelines for ceiling fans in typical buildings (i.e. flat or slanted ceiling) exist; however, none exist for abnormal ceiling configurations (i.e. sloped or rounded ceiling). These guidelines could improve fan placement and performance in environments with no uniform flat or sloped ceilings.

Research Question: How do placement guidelines for single and multiple ceiling fans change with irregular room and ceiling configurations where the fans cannot be placed equidistantly apart?

Primer Location: Sizing & Placement: pg. 38-49

5.5 MULTIPLE FAN AIR MOVEMENT

Priority: **5**

Gap Description: The air movement from multiple ceiling fans creates a pressure zone which forms when the two fans' air movement converge. This pressure zone behaves like a wall, where air rebounds off and is pulled upward. The air movement and area of coverage may change when occupants are present within these pressure zones. Currently, no research exists to explain this impact. Research on this topic could improve the placement of fans to reduce disruptions in air flow.

Research Question: What is the effect of occupants in a space on the air movement of multiple ceiling fans and how are pressure zones affected?

Primer Location: Flat Blade Air Movement, Foil Blade Air Movement: pg. 24-25, 29

5.6 AIR PROFILES BY APPLICATION

Priority: **5**

Gap Description: Fan air movement profiles vary by room type, design and furniture layout. Additional research could be conducted around how air movement and speed profiles change by room type and furniture layout in residential, classroom and office settings. This research could lead to more effective and targeted fan sizing and placement decisions.

Research Question: How do air movement and speed profiles vary for different room types in residential, commercial and industrial settings?

Primer Location: Flat Blade Air Movement, Foil Blade Air Movement: pg. 24-25, 29

6.1 AIR SPEED PROFILES

Priority: **6**

Gap Description: Fan shape affects how air is moved, shaping the area of influence or the area of effective cooling. Air speed profiles reveal fan air movement patterns, allowing practitioners to place fans in a way that ensures maximum area coverage. These air speed profiles are impacted by fan speed, type (i.e. standard, hugger, HVLS), size (fan diameter), location and the unique design characteristics of manufacturers (i.e. materials used, quality of materials). While air speed profiles exist for a few fans, they do not exist for all fan types, sizes, and manufacturers. More information would be needed to determine proper fan placement for additional fans.

Research Question: How do average air speed profiles change by fan type, blade type (i.e. flat, foil, HVLS), by size, and by manufacturer?

Primer Location: Air Speed: pg. 5, 29-30

6.2 BLADE QUANTITY & PITCH

Priority: **6**

Gap Description: Blade quantity, width and pitch affect ceiling fans' ability to redirect air downward and circulate air. Additionally, the space where the fan is placed, volume, height and additional equipment and layout obstructions impact air movement. Four blade fans and an 8-10 or 12-15 degree pitch are recommended in residential spaces for optimal ceiling fan performance; however, there is no similar recommendation for commercial and industrial spaces. These spaces are generally larger with different activities than residential spaces. Research is needed to determine which blade quantity, width and pitch optimizes air flow in these types of environments.

Research Question: How does blade quantity, size, width and pitch impact system performance in commercial and industrial applications?

Primer Location: Blade Shape, Quantity & Pitch: pg. 18

6.3 STANDARDIZED AIR MOVEMENT & SPEED PROFILES

Priority: **6**

Gap Description: Air movement and speed profiles differ by fan, blade type (i.e. flat, foil blades) and shape. Blade shape has evolved from flat or slightly curved blades to airfoil blades to increase efficiency, and the air speed profiles associated with these blade shapes are often left out. Research into air movement and speed profiles for different blade types would provide practitioners with the necessary information to properly place fans to maximize their impact.

Research Question: How do flat and airfoil blade shapes impact standardized air movement and speed profiles?

Primer Location: Flat Blade Air Movement: pg. 24-25

6.4 AREA OF INFLUENCE

Priority: **6**

Gap Description: The area of influence or the effective cooling area of a ceiling fan radiates with a generally uniform profile from the fan to the space below. However, obstructions such as furniture or other ceiling equipment can change the uniform profile, resulting in non-uniform areas of influence, which may enhance or detract from the intended profile. Research on the impacts of obstructions on an area of influence could help inform changes to fan designs to ensure intended performance.

Research Question: How does furniture or other obstructions affect ceiling fan areas of influence?

Primer Location: Airfoil Blade Air Movement: pg. 30

6.5 RETROFIT OPPORTUNITIES

Priority: **6**

Gap Description: Retrofits can be used to make fans more efficient and improve air movement by decreasing wind turbulence at the blade tip. Retrofits such as adding winglets to the fan or changing blades are being used in the airline industry to improve the fuel efficiency of aircraft. To date, ceiling fan manufacturer research has focused primarily on new fan design, missing an opportunity to enhance existing fans at a low cost through retrofits. Additional research could be conducted to understand the best designs for retrofitting ceiling fans.

Research Question: How can existing fans be retrofitted to increase air flow efficiency (CFM/W)?

Primer Location: Design, Sizing & Placement, Operations: pg. 6-34; 54-66

THiNK^{MK}

1500 Sansome Street, San Francisco, California 94111
mkthink.com | office@mkthink.com | 415.402.0888