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# PREFACE

In the digital age, the rapid advancement of design technology has led to changes in architectural designs. This change has brought a more holistic perspective to architectural designs. In our book, especially thermal comfort in architecture, technology in space perception, digital transformation in architecture, measurement of air quality with the internet of things, and architectural criteria of renovated boutique hotels are examined in detail. In this context, our book titled "ARCHITECTURE APPLICATIONS" is a study that will contribute to both architecture professionals and everyone who is interested in the subject.

This book named "**ARCHITECTURE APPLICATIONS**" consists of five chapters. In the book, the topics "Exploring Quantitative Analysis of Thermal Comfort in Architecture as a Positivist Research Paradigm", "The Role of Technology in the Formation of Spatial Perception", "BIM and Energy Efficiency: Digital Transformation and Sustainability in Architecture", "IoT-Based Air Quality Monitoring for Environmental Sustainability", "Architectural Value Criteria for Renovated Boutique Hotels", "The Future of Architectural Presentation Techniques: Augmented Reality" are discussed in detail. We would like to thank the authors, the referees of the chapters, BIDGE Publishing House and all those who contributed to the completion of the book. The book "**ARCHITECTURE APPLICATIONS**" will be useful to readers.

**Editor**

Prof. Dr. Murat DAL

# Content

# CHAPTER I

# Exploring Quantitative Analysis of Thermal Comfort in Architecture as a Positivist Research Paradigm

**Ali Berkay AVCI**[1]

## 1. Introduction

Thermal comfort is crucial role in enhancing the quality of life for individuals residing or working in indoor spaces by influencing their productivity, health, and overall well-being (Ganesh, Sinha, Verma, & Dewangan, 2021). Therefore, understanding and optimizing thermal conditions within built environments are important for ensuring comfortable and conducive living and working environments (Xu & Lian, 2024). This chapter focuses on the quantitative analysis of thermal comfort within the framework of a positivist research paradigm. The study elaborates on the objective measurement and analysis of physical and

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physiological factors that contribute to human comfort in indoor environments by examining thermal comfort evaluation through a positivist lens. Through a critical exploration of the rational model of thermal comfort evaluation, the chapter highlights the role of standardized variables, controlled experiments, and statistical analysis in understanding and optimizing thermal conditions for building occupants. The study provides a detailed examination of methodologies, critiques, and implications for research practice in the field of thermal comfort evaluation by narrowing the focus to the positivist approach.

Thermal comfort is a critical aspect of indoor environments, particularly as urbanization trends continue to rise, with an estimated 55% of the global population residing in urban areas, which is projected to increase to 68% by 2050 (United Nations, 2018). This shift emphasized the increasing significance of understanding and optimizing thermal conditions within built environments, where individuals spend a significant portion of their lives (Avci & Beyhan, 2020). Architects and engineers have long recognized the importance of thermal comfort in enhancing the quality of life for building occupants, aligning with the exploration of re-evaluating urban living conditions and the integration of technology to shape contemporary lifestyles (Pekdoğan, 2022).

The primary aim of this study is to provide a comprehensive review and critique of thermal comfort evaluation approaches by focusing on their underlying principles related to physical, physiological, and psychological factors. This chapter aims to elucidate the diverse methodologies employed in evaluating thermal comfort and their implications for research practice by examining existing studies. In order to achieve this aim, the following research questions will be addressed:

- What are the various approaches used to evaluate thermal comfort in indoor environments?
- How do these approaches align with the underlying assumptions regarding individuals' physiology and psychology?

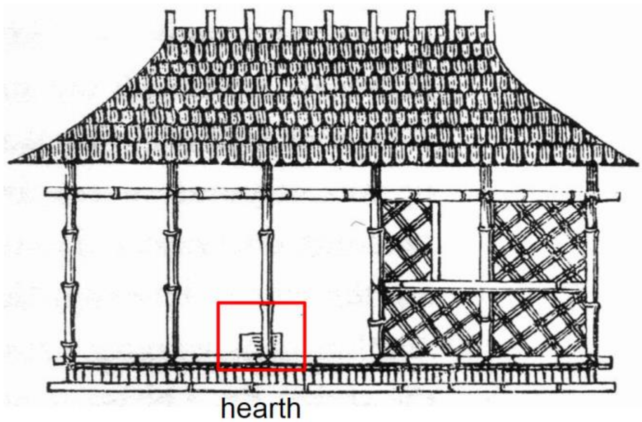
Thermal comfort, as defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), encompasses the satisfaction expressed by individuals with their thermal environment (ASHRAE, 2009). This definition acknowledges the multifaceted nature of thermal comfort, incorporating physical, physiological, psychological, and cognitive processes into its evaluation framework (Altomonte, Kaçel, Martinez, & Licina, 2024).

Thermal comfort evaluation approaches can be broadly categorized into rational and adaptive models, each offering distinct perspectives on assessing and optimizing indoor thermal conditions (Kwong, Adam, & Sahari, 2014; Sansaniwal, Mathur, & Mathur, 2022). The rational model, pioneered by P.O. Fanger, emphasizes the role of physical and physiological variables in determining thermal comfort (P.O. Fanger, 1967; Poul O Fanger, 1970). This approach relies on controlled experiments and standardized variables to quantify comfort levels, often yielding objective measures such as the Predicted Mean Vote (PMV) (Van Craenendonck, Lauriks, Vuye, & Kampen, 2018). In contrast, the adaptive model considers the dynamic interaction between individuals and their thermal environment, emphasizing real-world experiences and behaviors (R. J. De Dear, Brager, Reardon, & Nicol, 1998). This approach incorporates clothing choices, acclimatization, and subjective perceptions, offering a more nuanced understanding of thermal comfort (F. Zhang, de Dear, & Hancock, 2019).

A critical comparison of rational and adaptive approaches reveals significant disparities in their methodologies, assumptions, and applications (Sansaniwal et al., 2022). While the rational model prioritizes standardized variables and controlled conditions, the adaptive model emphasizes real-life experiences and individual preferences. These differences underscore the ongoing debate within the field of thermal comfort evaluation and highlight the need for further research to reconcile these contrasting perspectives (Kwong et al., 2014). This study aims to provide valuable insights for researchers and practitioners in the field of built environment design and optimization by examining the underlying principles and methodologies of thermal comfort assessment.

## 2. Definition and Importance of Thermal Comfort

Thermal comfort has been a fundamental issue in architecture since the human body started to shelter against exterior environmental conditions. In the illustrations of the primitive hut (Figure 1), the hearth is located at the center of the structure as a heating and cooking element, showing the importance of thermal conditioning (Koranteng, Afram, & Ayeke, 2015). Thermal comfort represents a multifaceted construct that encompasses physical, physiological, and psychological dimensions, influencing the overall satisfaction and well-being of individuals within indoor environments. As articulated in the seminal works of Fanger (1970) and subsequently endorsed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in their Standard 55 (2004), thermal comfort is defined as “the condition of the mind in which satisfaction is expressed with the thermal environment” (ASHRAE, 2020). This definition emphasizes the subjective nature of thermal comfort. It acknowledges that it is not only determined by objective environmental conditions but also by individuals' perceptions, preferences, and physiological responses (Crosby & Rysanek, 2021).




*Figrue 1. Carribean illustration hut by Gottfried Semper (Image credit: (Jacoby, 2015))*

The importance of thermal comfort evaluation in the design and management of indoor environments cannot be overstated (Marigo et al., 2023). With an increasing proportion of the global population residing in urban areas (United Nations, 2018), the quality of indoor environments has a profound impact on human health, productivity, and overall quality of life (Deng, Dong, Guo, & Zhang, 2024). Research indicates that suboptimal thermal conditions can lead to discomfort, stress, and reduced cognitive performance (Alfano, Olesen, Palella, & Riccio, 2014; Liddell & Guiney, 2015).

Therefore, optimizing thermal comfort is essential for creating indoor environments that support human well-being and productivity.

Thermal comfort evaluation is a critical tool for architects, engineers, and building managers seeking to design and maintain indoor spaces that meet the needs and preferences of occupants. By systematically assessing environmental factors such as temperature, humidity, air velocity, and radiant heat, as presented in Figure 2, researchers can identify optimal conditions for human comfort and well-being (Amaripadath, Rahif, Velickovic, & Attia, 2023). This multidimensional approach to thermal comfort evaluation recognizes that individual preferences and physiological responses change, which necessitates understanding the complex interactions between environmental factors and human perceptions (Pigliautile et al., 2020).

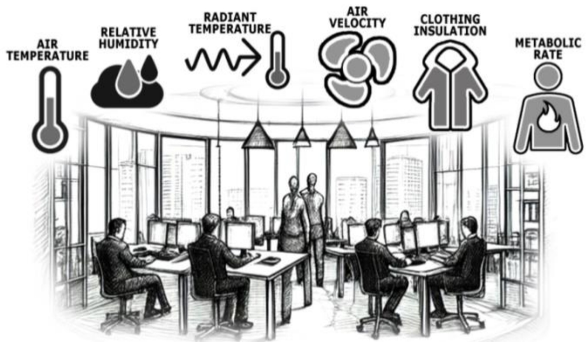



*Figure 2. Key factors for thermal comfort evaluation in buildings*

The significance of thermal comfort extends beyond individual comfort to broader societal and economic implications. Research indicates that comfortable indoor environments can lead to higher levels of productivity, satisfaction, and overall well-being among occupants (X. Zhang, Du, & Chow, 2023). Conversely, poor thermal conditions can result in increased absenteeism, reduced productivity, and negative health outcomes (Elnaklah, Ayyad, Alnusairat, AlWaer, & AlShboul, 2023). Therefore, investments in optimizing thermal comfort can give positive returns in terms of improved occupant satisfaction, health, and productivity, which will contribute to the overall success and sustainability in architecture.

Thermal comfort represents a complex and multidimensional construct that plays a crucial role in shaping the quality of indoor environments (Ma, Aviv, Guo, & Braham, 2021). By considering thermal comfort's physical, physiological, and psychological components, researchers and practitioners can develop strategies to optimize indoor environments for human well-being and productivity (Avci, Balci, & Basaran, 2024). As urbanization trends continue and the demand for comfortable indoor spaces grows, the importance of thermal comfort evaluation will only become more pronounced. This highlights the need for continued research and innovation in this critical area.

## 3. Rational Model of Thermal Comfort Evaluation

The rational model of thermal comfort evaluation relies on a systematic analysis of physical and physiological properties to assess and quantify human comfort within indoor environments. This approach considers key variables such as metabolic rate, clothing insulation, air temperature, relative humidity, and mean radiant temperature to determine thermal comfort levels, as developed by P.O. Fanger in the 1970s (P.O. Fanger, 1967; P O Fanger, 1973; Poul O Fanger, 1970). Researchers aim to create a standardized framework for understanding and optimizing thermal conditions for building occupants by examining these factors.

Controlled experiments, standardized measurements, and statistical analysis formed the backbone of the rational model's methodology (d’Ambrosio Alfano, Ianniello, & Palella, 2013). The equations were elicited by the controlled experiments conducted in a laboratory setting, which facilitated the manipulation of environmental variables such as temperature and humidity to observe their effects on human comfort (P.O. Fanger, 1967; P O Fanger, 1973; Poul O Fanger, 1970). Standardized identifications of variables such as metabolic rate and clothing insulation for typical indoor environments allow for consistent and reproducible data collection and statistical analysis, which enable researchers to identify patterns and correlations within the data (Yao et al., 2022).

The Predicted Mean Vote (PMV) scale is central to the rational model, which quantifies thermal comfort conditions on a numerical scale ranging from -3 to +3 (Ekici, 2013). This scale accounts for various environmental factors and individual physiological responses to determine an overall comfort rating. However, it is important to note that even in ideal conditions where all variables fall within predefined levels, a certain percentage of individuals may still experience discomfort, as indicated by the Predicted Percentage of Dissatisfied (PPD) metric (Djongyang, Tchinda, & Njomo, 2010). Despite its widespread use, the PMV scale has been criticized and debated regarding its ability to accurately capture the complexity of human comfort experiences (Humphreys, 1978; Lamberti, 2021).

Critics of the rational model argue that its reliance on standardized variables and controlled experiments may oversimplify the complex nature of human comfort (Du et al., 2022; Omidvar & Kim, 2020). The rational model may overlook the role of psychological and contextual factors in shaping individuals' comfort perceptions by focusing primarily on physical and physiological factors (Schweiker et al., 2012). Additionally, the rational model's emphasis on objective measurements may fail to account for subjective variations in comfort preferences and experiences, leading to discrepancies between predicted and actual comfort levels (Kim, Lim, Cho, & Yun, 2015).

Moreover, the rational model's limitations in predicting human comfort based solely on physical and physiological factors have been highlighted in empirical studies (Brager & de Dear, 1998; Doherty & Arens, 1988; Omidvar & Kim, 2020). Research indicates that individuals' comfort perceptions are influenced by factors beyond environmental conditions, including personal preferences, past experiences, and cultural backgrounds (Halawa & van Hoof, 2012). Therefore, while the rational model provides a valuable overview of the physical determinants of thermal comfort, it may offer an incomplete picture of the human comfort experiences.

In short, while the rational model of thermal comfort evaluation offers a systematic framework for understanding and optimizing indoor environments, it is not without its critiques and limitations. Researchers can develop more comprehensive approaches to thermal comfort evaluation that better reflect the preferences of occupants by acknowledging the complexities of human comfort and considering a broader range of factors beyond physical and physiological variables.

## 4. Adaptive Model

The adaptive thermal comfort approach is based on the premise that individuals naturally adjust to environmental changes to maintain comfort, emphasizing the dynamic interaction between occupants and their thermal environment (R. de Dear & Schiller Brager, 2001). Unlike the rational model, which relies on standardized variables and controlled experiments, the adaptive model considers real-world experiences and behaviors, recognizing that comfort is influenced by subjective perceptions and individual preferences (Luo, 2023).

The adaptive model adopts a systematic approach that integrates field studies, laboratory experiments, and validation techniques to assess thermal comfort (ASHRAE, 2020). Field studies involve observing occupants as they continue their daily activities in their natural environments, allowing researchers to capture the complexities of real-life thermal experiences (Halawa & van Hoof, 2012). These studies collect data on both physical environmental factors and occupants' subjective responses, often using survey methods to collect occupants' comfort votes along with objective measurements of environmental conditions. Simultaneously, physical data measurements complement subjective studies by providing reliable monitoring for validation purposes. Researchers can assess how individuals respond under different conditions and compare these findings to real-world observations by monitoring the variations in temperature, humidity, and other environmental factors (Čulić, Nižetić, Šolić, Perković, & Čongradac, 2021).

The adaptive comfort approach proposes that occupants' thermal expectations and preferences are influenced by contextual factors and their past experiences with temperature(Auliciems et al., 1998; R. J. De Dear et al., 1998). The adaptive model predicts comfort conditions based on individuals' adaptive behaviors and outdoor environmental conditions, drawing from field experiments conducted worldwide. Researchers examine factors such as clothing choices, activity levels, metabolic rates, and outdoor weather conditions to develop models that capture the dynamic nature of thermal comfort (Nicol & Humphreys, 1998). Researchers identify patterns and correlations between environmental variables and human comfort responses with the help of statistical analysis and empirical observations. As such, Figure 3 illustrates the required interior operative temperatures for 80% and 90% of the occupants' thermal acceptability rates in relation to the outdoor air temperature.

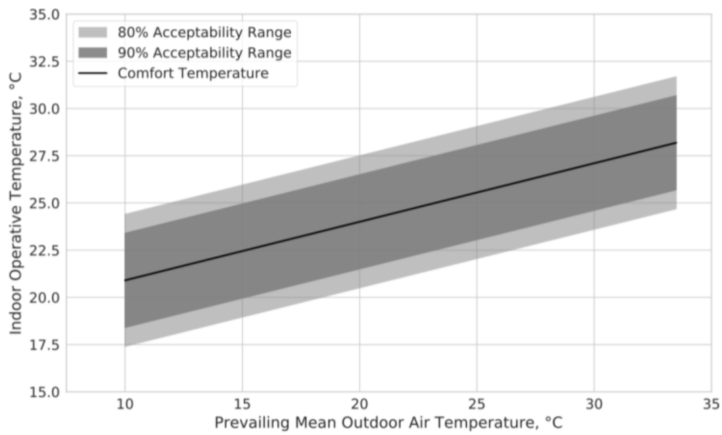



*Figure 3. Thermal acceptability ranges for adaptive model (ASHRAE, 2020)*

A key aspect of the adaptive model is its consideration of various factors contributing to adaptation, including behavioral, physiological, and psychological aspects (Jing, Li, & Yao, 2018). Behavioral adaptations encompass actions such as adjusting clothing, opening windows, or using fans to regulate thermal comfort, while physiological adaptations involve processes like acclimatization to prevailing environmental conditions (Luo, 2020). Psychological adaptations, such as individuals' expectations and past experiences, further influence their perceptions of thermal comfort.

While the adaptive model offers deep knowledge of the dynamic nature of thermal comfort, it is not without its critiques and limitations. Critics argue that the subjective nature of comfort assessments in field studies may introduce bias and variability into the data, making it challenging to generalize findings across different contexts (Schweiker et al., 2012). Additionally, the reliance on self-reported comfort votes and subjective perceptions may overlook objective environmental factors that contribute to comfort, leading to discrepancies between perceived and actual comfort levels (Song & Calautit, 2024). In addition, the adaptive model's reliance on subjective perceptions and individual behaviors may limit its applicability in certain contexts, particularly in controlled environments where occupants have limited autonomy. Besides, the adaptive model's emphasis on real-world experiences may create challenges for researchers seeking to establish causal relationships between environmental variables and human comfort outcomes. Unlike the controlled conditions of the rational model, adaptable environments may encounter confounding variables and external factors that complicate data interpretation and analysis.

Despite these limitations, the adaptive model offers important knowledge for the complexities of thermal comfort evaluation and provides a more holistic understanding of the interplay between environmental conditions and human experiences (Schweiker, Huebner, Kingma, Kramer, & Pallubinsky, 2018). More comprehensive approaches to thermal comfort evaluation can be developed that better reflect the diverse needs and preferences of building occupants by complementing the rational model with insights from real-world observations and subjective perceptions. Researchers and practitioners can adopt a more holistic approach to optimizing indoor environments for human well-being and productivity with a detailed understanding of both the rational and adaptive models of thermal comfort evaluation.

## 5. Implications for Research Practice

The positivist approach to thermal comfort evaluation carries significant implications for research design and practice. It details how quantitative analysis can inform building design, environmental policy, and human-centered interventions. Adopting a positivist perspective in thermal comfort evaluation requires rigorous research methodologies grounded in objective measurement and statistical analysis. Researchers employing this approach prioritize controlled experiments, standardized measurements, and quantitative data analysis to generate reliable and reproducible findings. By adhering to systematic research protocols, they aim to establish causal relationships between environmental variables and human comfort outcomes, providing valuable insights into the factors influencing thermal comfort within indoor environments. Furthermore, the positivist approach underscores the importance of interdisciplinary collaboration as researchers draw upon insights from architecture, engineering, environmental science, and psychology to develop comprehensive thermal comfort models.

Quantitative analysis within a positivist framework can offer practical guidance for building design and environmental policy (Amaratunga, Baldry, Sarshar, & Newton, 2002). The design of energy-efficient and comfortable indoor spaces can be identified by identifying optimal ranges for environmental variables such as temperature, humidity, and ventilation rates. Besides, knowledge gained from quantitative analysis can help policymakers develop evidence-based regulations and guidelines to enhance thermal comfort standards in building codes and standards (ASHRAE, 2009). For instance, optimization studies for the architectural components of energy efficiency and comfort contain the potential to integrate such strategies into environmental policy and building design (Bre & Fachinotti, 2017; Gercek Sen, 2023).

Additionally, the positivist approach highlights the importance of user-centered design principles, emphasizing the need to prioritize human well-being and satisfaction in architectural and engineering practices. By incorporating feedback from building occupants and conducting post-occupancy evaluations, designers can iteratively refine building designs to better align with users' diverse needs and preferences (Oseland, 2023). This iterative approach fosters continuous improvement and innovation in building design, ultimately creating more supportive and comfortable indoor environments.

When it comes to designing buildings and creating policies, studying comfort using analysis can help improve the well-being and productivity of occupants. Researchers can develop tailored strategies by pinpointing factors that affect how comfortable and productive people are, like control systems, personalized thermal solutions, and behavior change programs (Čulić et al., 2021). User feedback and subjective evaluations are crucial in informing design decisions and shaping indoor environments that foster comfort, satisfaction, and well-being (Rohde, Larsen, Jensen, & Larsen, 2020). These strategies enable individuals to customize their spaces based on their preferences and physical responses, leading to comfort, satisfaction, and productivity.

Innovations, in sensor technology like sensors, wireless networks and Internet of Things (IoT) devices have empowered researchers to gather data, on environmental factors and peoples physical reactions (“Wireless Sensor Networks, Internet of Things, and Their Challenges,” 2019). These advancements provide perspectives on how individuals engage with their surroundings' temperature, which enables researchers to observe fluctuating comfort levels and preferences. Implementing data analytics and machine learning algorithms, large datasets can be analyzed to identify patterns, correlations, and predictive models of thermal comfort (W. Zhang, Wu, & Calautit, 2022). Moreover, the integration of advanced sensing technologies with building management systems enables adaptive control strategies that dynamically adjust environmental conditions based on occupants' preferences and behavior.

Interdisciplinary collaborations are increasingly recognized as essential for advancing thermal comfort research and addressing complex challenges in building design and environmental sustainability. By bringing together experts from diverse fields, such as architecture, engineering, environmental science, psychology, and public health, researchers can leverage complementary expertise to develop holistic solutions to thermal comfort problems. Interdisciplinary collaborations facilitate knowledge exchange, innovation, and cross-pollination of ideas, leading to novel insights and approaches that transcend traditional disciplinary boundaries. Additionally, interdisciplinary teams are better equipped to solve complex issues like climate change adaptation, urban heat island mitigation, and energy-efficient building design by integrating expertise from multiple domains (Bibri, 2020).

Climate change holds significant challenges to thermal comfort in indoor environments, as rising temperatures and extreme weather events increasingly impact building performance and occupant well-being (Hosseini, Javanroodi, & Nik, 2022). Researchers are exploring innovative strategies for climate change adaptation, such as passive design techniques, green infrastructure, and resilient building materials, to mitigate the adverse effects of environmental stressors on thermal comfort (Cirrincione, Marvuglia, & Scaccianoce, 2021). Indoor environments that are resilient, adaptive, and sustainable in the face of climate change uncertainties can be created through integrating climate-responsive design principles and low-carbon technologies.

## 6. Conclusion

This chapter has comprehensively examined the quantitative analysis of thermal comfort within a positivist research paradigm. By focusing on objective measurement, controlled experiments, and statistical analysis, researchers employing this approach seek to enhance our understanding and optimize indoor thermal environments. Throughout this discussion, several key insights have emerged. First, thermal comfort is a multidimensional concept influenced by physical, physiological, and psychological factors. Comprehensive models of thermal comfort that account for the diverse needs and preferences of building occupants can be developed by considering these factors within a positivist framework,

Second, the rational model of thermal comfort evaluation relies on standardized variables and controlled experiments to quantify human comfort outcomes. Techniques such as the PMV provide valuable tools for objectively assessing thermal comfort conditions. However, criticisms of this model highlight its limitations in predicting human comfort solely based on physical and physiological factors, underscoring the need for a more holistic approach.

Future research should prioritize interdisciplinary collaborations and innovative methodologies to advance our understanding of thermal comfort. By integrating insights from fields such as architecture, engineering, environmental science, and psychology, researchers can develop more nuanced and context-sensitive models of thermal comfort that account for the complex interactions between environmental conditions and human experiences. The approaches to thermal comfort evaluation that integrate qualitative insights and participatory design methods need to be explored. Solutions that better align with users' diverse needs and preferences can be achieved by engaging building occupants as active participants in the research process. This will ultimately lead to more supportive and comfortable indoor environments.

In conclusion, the quantitative analysis of thermal comfort within a positivist research paradigm offers valuable opportunities to enhance our understanding and optimization of indoor thermal environments. Using different research methodologies and interdisciplinary collaborations, researchers can develop evidence-based practices that promote well-being, productivity, and sustainability for all occupants.

## Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work the author used Grammarly GO AI Writing Assistant to improve language and readability. After using this tool, the author reviewed and edited the content as needed and take full responsibility for the content of the publication.

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