



Thermal Ergonomics and Underfloor Air Distribution Systems

Underfloor Air Distribution Technology (UFAD) has been around for many years and has some clear advantages for users, over traditional ceiling fed systems. UFAD is often overlooked due to project team unfamiliarity and perceived complexity, although now the current trend in building design is focused on sustainability and wellbeing, choice perception could improve. John Hargreaves, senior ergonomist from HAM will discuss key thermal ergonomics principles from a user centred design perspective.

Thermal comfort is often the most challenging aspect of workspace environments, with a complex set of parameters to consider in support of the human bodies thermal balance. The British Standard for thermal ergonomics (7730) defines measurement techniques for indoor environments using the predicted mean vote (PMV) and percentage of dissatisfaction (PPD) models. We have developed an ergonomics survey tool HUSI™, that defines a quantitative measure of reported satisfaction from a user perspective. This approach is easy to deploy and yields a rich data set to understand the impact workspace environments have on people and can compliment PMV and PPD.

Ergonomics is the science of work and ergonomics design applies human factors to deliver a better fit between people process and technology. As an ergonomics practitioner, I have encountered a variety of mechanical air handling systems and collected comments from staff about the impact on comfort and performance. Key complaints often centre around temperature being either too hot or too cold or problem drafts at certain points of the room. There can be dry or stale pockets of air, dirt and dust perception and when systems are poorly set up with a lack of control, this creates on going problems, often hidden in the busyness of work routines.

The aim of this **ergonomics briefing** is to discuss the benefits of UFAD, refocusing the engineering of air handling systems onto a balanced **human-machine perspective**. We critically highlight the importance of delivering better workspace systems, with reference to the UFAD design guide, research papers and experience of running staff face-to-face interviews. (See references [1] at the end of this document).

TABLE OF CONTENTS

1.0 Brief background to the ergonomics of the thermal environment	Page 2
1.1 Targeting Satisfaction.....	Page 3
1.2 Impact on staff wellbeing comfort and performance.....	Page 4
2.0 Underfloor Air Distribution Systems (UFAD).....	Page 7
3.0 Conclusions.....	Page 9
Appendix A: Key References.....	Page 10

1.0 A brief background to the ergonomics of the thermal environment.

- 1) The full title of BS 7730 '**Ergonomics of the thermal environment, analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort**', suggests complexity. It states that 'human thermal sensation' is mainly related to the 'thermal balance of the whole body', influenced by 'physical activity and clothing' as well as 'environmental parameters', 'air and radiant temperatures', 'velocity and humidity' [4].
- 2) These variables directly affect core physiological processes such as heat exchange and body temperature regulation, key to maintaining a thermal balance. Despite these complexities, individual control over the immediate environment can also play a significant role in determining thermal comfort. **This key ergonomics point should not be lost during system design, when carrying out the detailed calculations for PMV and PPD.**

“Research evidence suggests that occupant satisfaction and productivity can be increased by giving individuals greater control over their local environment” [3].
- 3) The Predictive Mean Vote (PMV) was developed by P.O. Fanger [7] in the 1970s and is widely referenced in other standards like ASHRAE 55 [2]. The PMV predicts the average thermal sensation of a large group of people on a 7-point scale, exposed to the same environment. The PPD can then be calculated from the PMV to establish a 'quantitative prediction of the percentage of thermally dissatisfied people' [4]. This provides an effective engineering-based model to measure and predict user dissatisfaction. One potential short coming of this approach is that it bypasses user opinion, although this is obviously unavoidable for new buildings!
- 4) To determine PMV and PPD for an existing system, a carefully controlled environmental survey needs to be undertaken to collect a number of key thermal inputs, using calibrated monitoring equipment and observations about the occupants and their work. Data is recorded across various points in the workspace with key inputs being, clothing, metabolic rate, air temperature, radiant temperature, air velocity and humidity.

Regardless of the ergonomics approach used, a key objective must be to target satisfaction and we will look at this next.

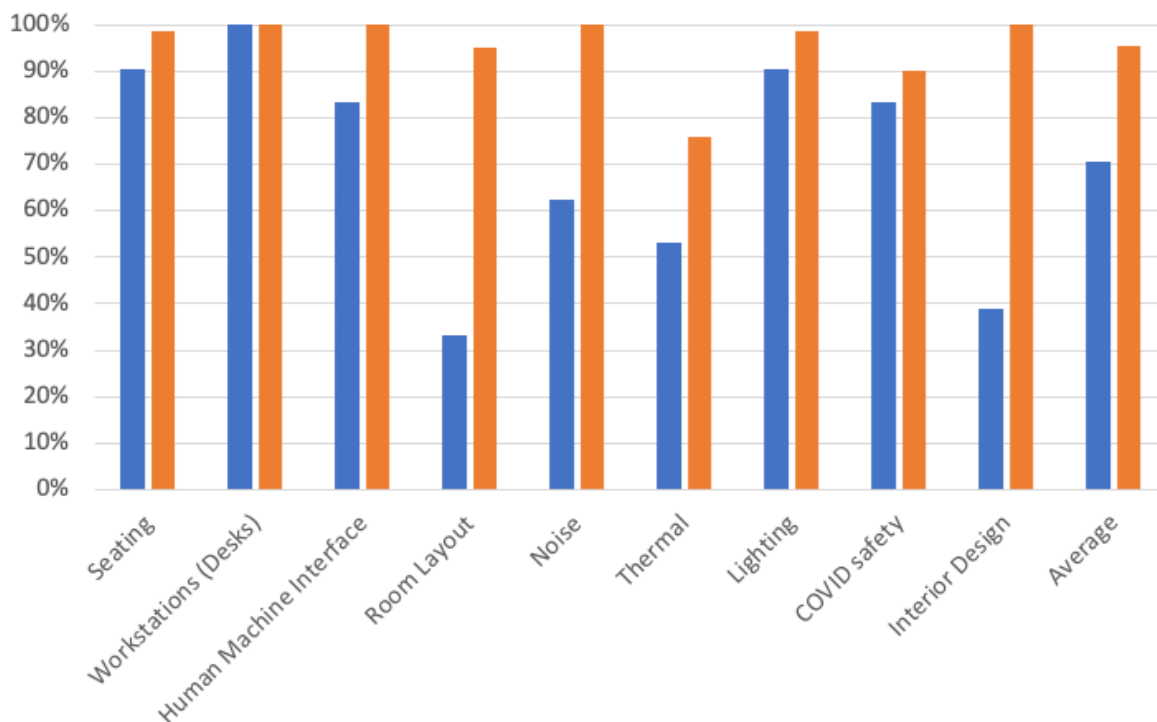


Figure 1: Workspace satisfaction ratings before and after an ergonomics design project.

1.1 Targeting satisfaction

- 1) Running user centred design projects provides feedback on workspace features and is an excellent way to understand the impact on comfort and performance. The bar chart above is taken from a HAM project survey, with blue being the baseline and orange after refurbishment changes. You can clearly see that the thermal environment has one of the lowest satisfaction ratings of all elements. In my experience, this element often gets lower satisfaction ratings as users are more sensitive to air movement and temperature. This tends to confer with Wyon [14] who carried out a study showing perceived productivity gains in relation to control over key environmental conditions. The study showed that users felt control over the thermal environment affected their productivity the most.
- 2) Although the PMV model mentioned earlier can be used to check whether a given thermal environment complies with comfort criteria, staff surveys provide an actual measure of success. PMV can also be used to define the requirements for a new system, by estimating the key thermal inputs. However, 'Due to individual differences, it is impossible to specify a thermal environment that will satisfy everybody and there will always be a percentage of dissatisfied occupants' [4]. It is however possible to 'satisfy a a percentage' [4] and based on HAM experience a target of 80% is a realistic target to used.
- 3) BS 7730 defines categories for satisfaction based on PPD;
 - **Category B:** $PPD \leq 10\%$, which corresponds to approximately 90% satisfaction.
 - **Category C:** $PPD \leq 15\%$, which is closer to 85% satisfaction.
- 4) The ASHRAE standard 55 [2] defines conditions under which at least 80% of occupants will find the environment thermally acceptable. The 80% satisfaction threshold is explicitly embedded in the standard, using PMV, PPD and adaptive comfort models. For an 80% satisfaction rate, a PPD just under 20% is acceptable and comparable to ASHRAE, hence using this as a target for satisfaction across all workspace features seems to be prudent.
- 5) Using PMV, PPD and User surveys will provide the best overall understanding of thermal comfort, once a workspace has been established. This will enable an optimum solution to be delivered within project constraints. **To understand why this matters, we need to look at the impact on staff wellbeing, comfort and performance and we will tackle this next.**



Figure 2: John Hargreaves running workspace surveys with staff.

1.2 Impact on staff wellbeing, comfort and performance

- 1) An inappropriate thermal environment may contribute to the overall stress of an employee. Stressed people fatigue more quickly and are less likely to tolerate minor annoyances in the work environment or interactions with colleagues. Therefore, environmental features such as air quality, may suddenly become intolerable when an individual is under a high stress load [10].
- 2) Being too hot or cold can distract staff from their tasks by reducing manual dexterity and impairing concentration, causing a reduction in task performance. Studies have shown that manual dexterity is worse under cold conditions, mental performance decreases with heat and in general, performance is optimum when occupants are thermally comfortable. Being thermally comfortable is a subjective condition, which is affected by activity, clothing levels and control over internal environmental systems. Studies have also shown that heat and a lack of fresh air can cause lethargy and seriously affect productivity [10].
- 3) Providing individual control may be necessary to produce the feeling of optimum conditions for comfort. Several studies have shown that the less the perceived control, the more occupants will say their productivity is reduced. Wyon also showed that control over temperature yields the best productivity gains; control over ventilation is next in importance, then control over lighting (See Figure 3 on next page) [14].

Studies have shown that heat and a lack of fresh air causes lethargy and may seriously affect productivity.

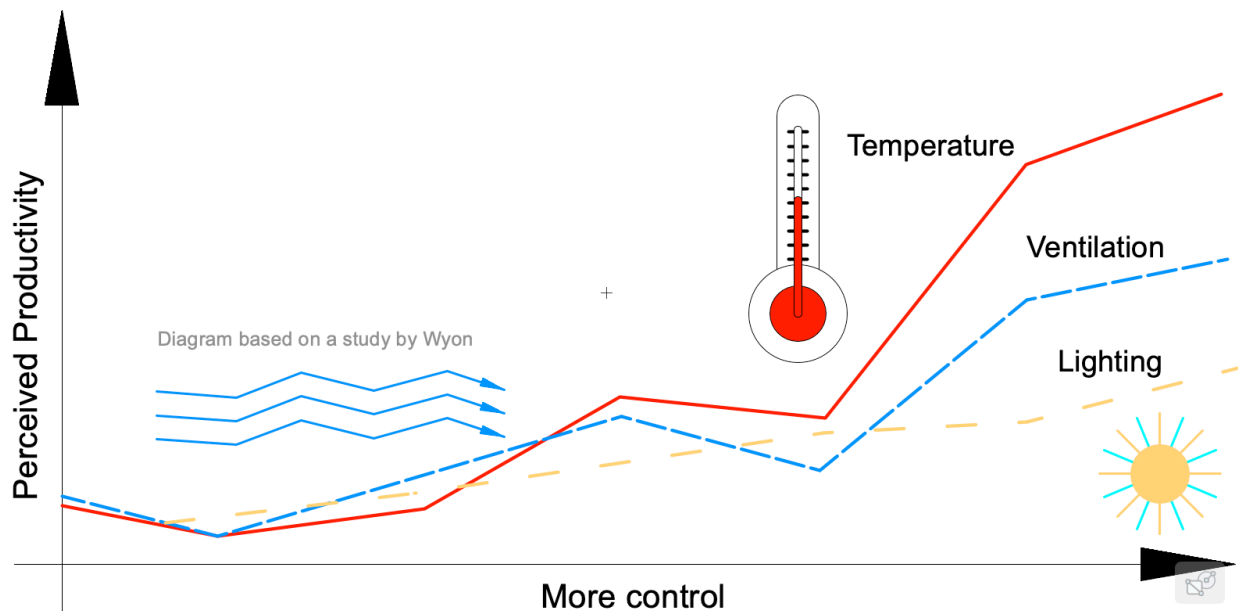


Figure 3: Study showing perceived productivity gains in relation to key environmental conditions.

4) There are several key environmental factors affecting thermal comfort [4];

- **Air Temperature:** The most commonly monitored metric, but not sufficient on its own.
- **Radiant Temperature:** Influences perceived heat from walls, ceilings, and equipment.
- **Air Velocity:** Can cool or overcool depending on speed and direction.
- **Humidity:** Affects the body's ability to sweat and cool and use of vocal/visual systems.
- **Clothing Insulation:** Determines how well the body retains or loses heat.
- **Metabolic Rate:** Varies with activity level and affects heat production.
- **Control:** A lack of control over the thermal environment particularly temperature can act as a significant additional stressor in the workplace.

1.2.1 Air Temperature

- 1) Temperatures which are perceived to be unsuitable, either too hot or cold can contribute to the overall stress of an employee. This can be especially true when staff deal with difficult or abusive callers in an emergency call handling environment. Being in a stressed state can impair judgement, increase errors and reduce response times especially when dealing with difficult or life-threatening events. These issues will probably have a negative effect on other types of workspace user who are performing critical tasks for an organisation with the pressure of work deadlines within a large team [10].
- 2) Lower air and surface temperatures can increase the risk of RSI of the hands and arms if awkward postures, repetitive movements and inadequate rest breaks are adopted. This is due to physiological and biomechanical factors causing muscle and tendon stiffness, slower nerve signals making awkward movements and diminishing tactile sensitivity leading to excessive force being used when typing [10].

1.2.2 Radiant Temperature

- 1) Radiant temperature refers to the heat emitted from surrounding surfaces such as walls, ceilings, windows, and equipment. If a user is seated near a cold external wall or large unshaded glazing, they may experience localised cooling or heating that affects overall thermal comfort, even if the air temperature is within acceptable limits [10].

- 2) Asymmetrical radiant temperatures, where one side of the body is significantly warmer or cooler than the other, can cause thermal discomfort and muscular strain, especially when sustained for long periods. For example, intense heat from nearby electronic equipment or sunlight through windows can result in thermal hotspots, encouraging poor postures as users shift to avoid discomfort [10].

1.2.3 Air Movement

- 1) Excessive air movement can cause draughts and may lead to musculoskeletal problems. Draughts (depending on the temperature) can cause muscular pain of the neck and shoulders if the velocity is sufficiently high. Draughts can also contribute to dry or sore eyes depending on the velocity and the direction of the air stream [10].

1.2.4 Humidity

- 1) Low Relative Humidity (RH) can dry eyes, nasal passages and skin. RH below 30% is associated with drying of the mucous membranes, increased respiratory discomfort and static shocks. Intensive display screen users are prone to complaining of dry and sore eyes at low humidity levels as the concentration intensity with display monitors decreases the blink rate and increases tear evaporation [10]
- 2) In low humidity environments, dry eyes can become increasingly common with the use of contact lenses that rely on the tear level of the eye. Intensive communications in a low humidity environment is associated with drying of the mucous membranes, of the respiratory system, contributing to dry throats and noses. This can reduce the communication performance of staff [10].

1.2.5 Clothing Insulation

- 1) Clothing acts as a barrier to heat exchange between the body and the environment. If clothing is too insulating in a warm environment or too light in a cool one, the body must work harder to regulate internal temperature, leading to discomfort and stress. This is particularly relevant in mixed-activity workspaces or shift environments where users cannot easily adjust clothing [10].
- 2) Inconsistent clothing insulation across a team can lead to varying comfort experiences, which may increase the likelihood of thermal complaints and dissatisfaction with the environment. Workplaces with uniform requirements, such as emergency call centres or customer-facing staff, must take likely insulation levels into account when designing HVAC systems or zoning local conditions [10].

1.2.6 Metabolic Rate

- 1) Metabolic rate reflects the amount of heat generated by the body based on activity. In office environments, the typical metabolic rate is around 1.0 met (seated, light activity), but it may vary with stress levels, posture, or incidental movement. Increased mental workload or emotional stress (e.g. handling difficult calls) can subtly elevate metabolic rate, increasing sensitivity to heat and thermal discomfort [10].
- 2) If the thermal environment does not account for the metabolic demands of the task (e.g. prolonged seated work under cognitive stress), it can reduce concentration, impair decision-making, and increase error rates. Ergonomic planning must recognise that even mentally intensive work affects heat balance and thermal needs, particularly in performance-critical environments [2,9,10,12].

1.2.7 Control over the environment

- 1) A lack of control over the thermal environment particularly temperature, can act as a significant additional stressor in the workplace. When individuals feel unable to regulate their comfort, they may adopt a range of coping strategies. These can include taking more frequent breaks, adjusting their clothing layers, relocating within the room, using personal heating or cooling devices, reducing physical or cognitive effort, or withdrawing socially. If these efforts fail to alleviate the discomfort, prolonged exposure can contribute to increased stress levels, decreased productivity, and in some cases, longer-term health consequences such as fatigue, headaches, or musculoskeletal strain [10] **Providing some user control over air handling systems within defined parameters is critical to success. We will look at how UFAD technology can support this in the next section.**

2.0 Underfloor Air Distribution Systems UFAD

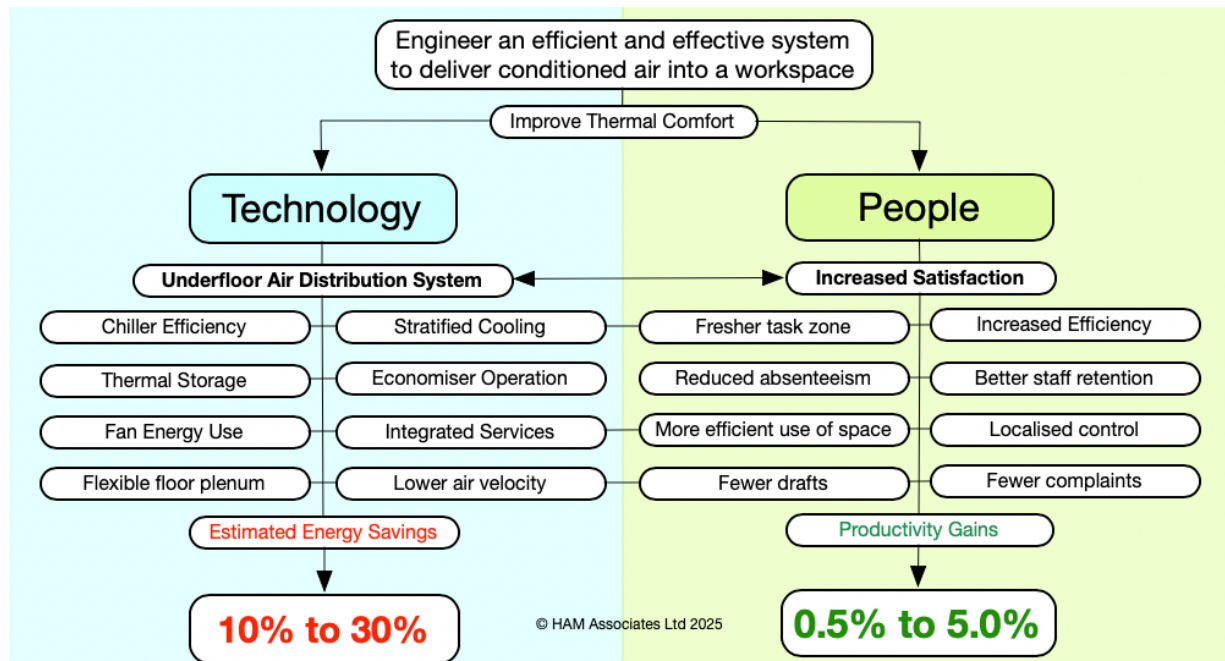


Figure 4: UFAD systems can be more energy efficient and support productivity.

- 1) The benefits of using UFAD systems are well documented and grounded in user comfort and performance [3]. A key feature of this technology is the use of a floor plenum allowing conditioned air to enter the room directly into the task zone (See figure 5). The approach can also take up less space and be more energy efficient than traditional ceiling fed systems. The diagram above, represents a more balanced human-machine summary of UFAD technology, relating energy savings to comfort, performance and productivity.
- 2) A key feature of UFAD is the delivery of **conditioned air directly into the occupied zone**, rather than mixing it from the ceiling down. This enables a naturally superior **floor-to-ceiling airflow pattern** with the following benefits:
 - Supports **personalised comfort control** at individual workstations.
 - Promotes **thermal stratification**: warm, polluted air rises and is removed at ceiling level.
 - Keeps **cleaner, cooler air** in the plan zone.
 - Reduces **energy consumption** by not cooling the unoccupied upper room volume.
- 3) With an overall objective of 'engineering an efficient and effective system to deliver conditioned air into a workspace', the real impact on people is usually overlooked and is arguably the larger cost, much harder to quantify and sitting in another budget! The users are often accused of 'always complaining' or 'not knowing what they really want', although the likely cause of this is an unbalanced thermal system with lack of user control. **With sustainability and wellbeing becoming fundamental concepts, reconsidering the approach to air handling is important, especially with critical rooms that have a high heat load and cannot be supported by passive cooling.**

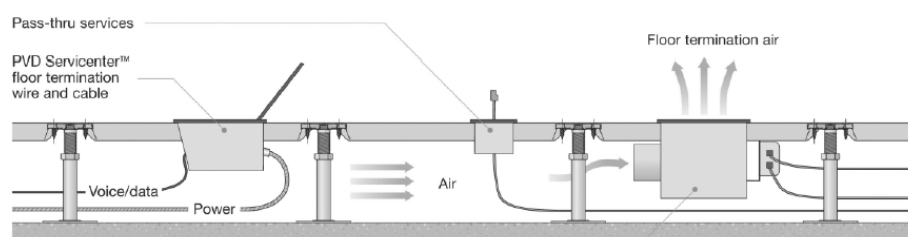


Figure 5: Installation of a raised floor system creates an integrated plenum (Image from UFAD design guide)

- 4) Before delivering a new UFAD system, it is worth considering several key points;
- The specification is very important as the system needs to deliver control over air temperature, velocity and humidity whilst enabling stratification with flexibility for future changes.
 - Ensuring some localised control over any air handling system is critical to success.
 - Filtration is important to maintain air quality, removing dust, allergens and bacterial pollutants.
 - Placement of floor inlet grills must be carefully defined ready for furniture arrangements.
 - Placement of extract grills should ideally be at high level to enable stratification.
 - If mechanical plant needs to be installed in the workspace, cabinets should be specified to ensure noise and vibration is minimised.

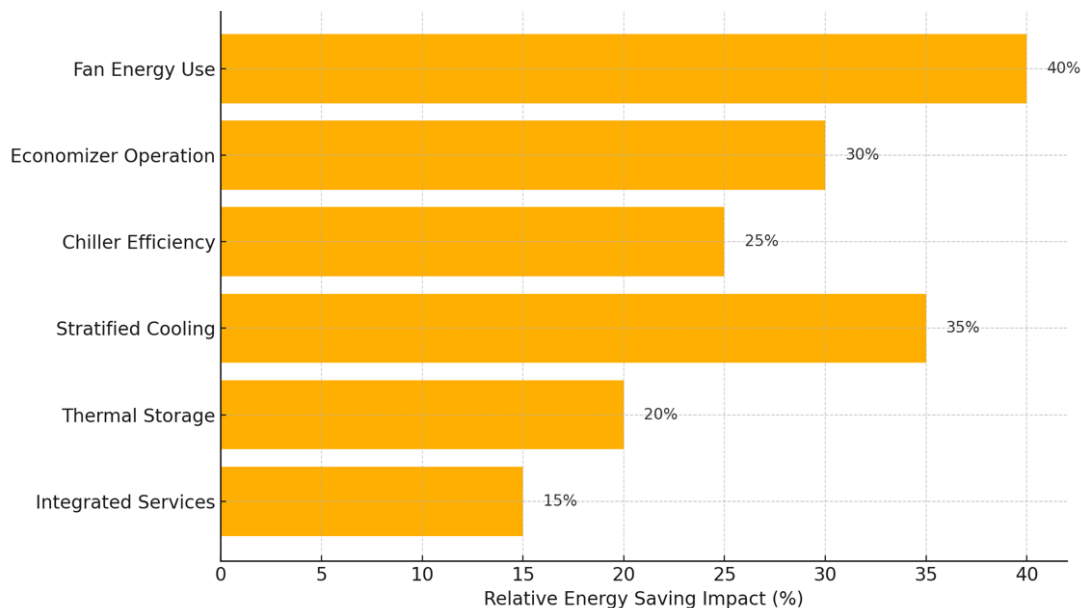


Figure 6: UFAD Energy Efficiency Advantages over Overhead Systems

- 5) The **energy efficiency** of UFAD compared to conventional overhead systems is supported by several key pieces of evidence from the *UFAD Design Guide* [3] and related research. UFAD systems represent important technological solutions that are often overlooked. It is estimated that UFAD systems can deliver between 10%-30% energy savings when compared to more traditional ceiling-based systems. The bar chart above shows an average estimated energy and build cost savings for key dimensions, taken from the UFAD design guide [3].

Fatronic

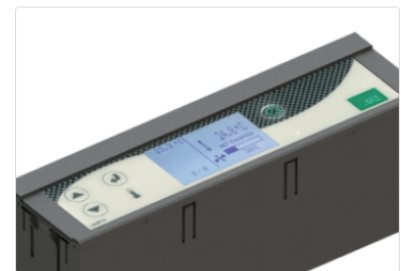


Figure 7: Integrated controller for fan terminal units from AET.

- 6) Local control is critical as 'cognitive' effort generates heat and when people are focused on demanding mental tasks, such as; decision-making, problem-solving, or emotional labour their brain metabolism increases, subtly raising body temperature [9]. This can lead to a heightened individual perception of warmth, even in stable ambient conditions. In high-pressure roles, thermal sensitivity becomes more pronounced [11] making local temperature control an essential ergonomic feature. Task/ambient conditioning (TAC) systems can be used to provide control over local conditions without disturbing other occupants [3]. Companies like AET Flexible Space, can supply integrated controllers for fan terminal units allowing individual user control with their UFAD systems (Figure 7).

- 7) The main page image shows desks are being positioned in a critical workspace that has been subject to a refurbishment. The room had an existing UFAD system with a plenum floor, allowing for flexible repositioning of existing air inlet grills around a new ergonomic room layout with changes made to support new team working interactions. As the system is controlled centrally, it does restrict satisfaction, although the relevant authority has another centre with an overhead system where satisfaction is reported to be much lower.

Occupant satisfaction and productivity can be increased by providing individual control.

3.0 Conclusions

- 1) Thermal comfort of users is an important issue when designing or improving workspaces. A standard engineering approach is unlikely to yield appropriate satisfaction ratings of 80%. It is critical that project teams embarking on new or refurbished workspace projects, take a socio-technical system view when designing air handling systems. Project teams should consider using workspace ergonomics, and satisfaction surveys to help deliver fit for purpose solutions
- 2) UFAD systems have the potential to reduce cost not only from a building services perspective but also in relation to staff productivity. These systems are more able to provide conditions that users will find thermally satisfying. If project teams are considering a significant refurbishment or new build project, it is worth considering the selection of UFAD technology or at least making targeted improvements to existing systems based on the ergonomics of thermal comfort. If existing systems are left alone with unbalanced thermal conditions, this will simply add an extra layer of stress or distraction, affecting staff wellbeing, comfort and performance.



John Hargreaves has been supporting project teams and users with ergonomics design and human factors for over 30 years. He has an excellent understanding of how to deliver solutions that integrate people, process and technology. John always takes a user centred approach and aims to deliver 'fit for purpose' solutions improving the health, safety, comfort and performance of the many staff groups he has supported.

For more information about workspace ergonomics please visit our website

www.ham.co.uk

HAM Associates Ltd. China Works, Black Prince Road, London SE1 7SJ.
www.ham.co.uk email: jh@ham.co.uk

Appendix A: Key References

1. **ASHRAE Handbook – Fundamentals (2021)**
2. **ASHRAE Standard 55-2020**, *Thermal Environmental Conditions for Human Occupancy*.
3. **Bauman, F.S, (2003)** American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2013. UFAD Design Guide.
4. **BS EN ISO 7730, (2005)**. Ergonomics of the thermal environment, analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort.
5. **BS EN ISO 9241, (1999)**. Ergonomics of Human System Interaction. Part 6: Guidance on the work environment.
6. **BS EN ISO 11064, (2006)**. Ergonomic design of control centres. Part 6: Environmental Requirements.
7. **Fanger, P.O. (1970)**. *Thermal Comfort: Analysis and Applications in Environmental Engineering*.
8. **ISO 9920:2007 – Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble**.
9. **Madsen, P. L., et al. (1995)**. *Persistent increase in cerebral oxygen consumption during recovery from sustained mental arithmetic task*.
10. **Murphy J, (2001)** HAM Ergonomics Environmental Assessment for HP CCR.
11. **Oka, Oka & Hori, 2001**; Mechanisms and mediators of psychological stress-induced rise in core temperature.
12. **Parsons, K.C. (2014)**. *Human Thermal Environments* (3rd ed.)
13. **Raichle, M. E., & Gusnard, D. A. (2002)**. *Appraising the brain's energy budget*. Trends in Neurosciences, 25(10), 560–561. (The brain consumes about 20% of resting metabolic energy, and activity-specific increases in demand are well documented).
14. **Wyon D.P, (1996)** “Indoor environmental effects on productivity,” presented at the ASHRAE IAQ '96 conference and published in the Proceedings of ASHRAE Conference on Paths to Better Building Environments.
15. **Zhai, Y., & Barreca, M. (2017)**. *Human thermal adaptation in the workplace*. (Explores how thermal comfort is shaped by psychological and behavioural factors, including task demands).