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## **RIVISTA ITALIANA DI ERGONOMIA**

*THE RIVISTA ITALIANA DI ERGONOMIA, of the S.I.E. - Italian Society of Ergonomics, is a scientific journal that operates nationally and internationally for the promotion and development of ergonomics and the study of human factors, and the dissemination and systematization of knowledge and experiences related to the ergonomic approach, in close relationship with the social, environmental and productive realities where human beings, operate and live, coherently with the goals of the SIE.*

*Supported by an international scientific committee and using a double-blind reviewing process, the journal publishes original contributions from research and applications on ergonomic issues, in its various aspects and related to the different contexts and human activities.*

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# EDITORIAL

ERMINIA ATTAIANESE



## The challenges of sustainable wellbeing in the Human Factors perspective

Human Factors/Ergonomics (HFE) and sustainability find a common ground in human wellbeing. In fact, in the HFE approach, wellbeing is the main design goal, that can be reached by optimizing the interactions among humans and any other designed system (IEA 2000). On the other side, the basic statement about sustainability, affirms that well-being is the goal that current generation's should protect and not harm, to leave to future generations (Bruntland, 1987).

However, since it is always related to the fulfilment of human needs, the reference framework of wellbeing is not fixed, but it is changing over the time sensitive to the context.

Today a number of global threats is fostering the emerging of new priorities and humans necessities to satisfy, that are modifying the concept of wellbeing. From the ego-centric model, the need of an eco-centric perspective is affirming, that is widening the concept of wellbeing for including both the protection of ecosystems and human prosperity, since it is evidenced that human health and well-being are tightly tied to that of animals, plants and the wider environment.

(Adisasmito, 2023; Ronen & Kerret, 2020).

Similar to health, wellbeing is currently seen as a resource for daily life, determined by social, economic and environmental conditions. It encompasses quality of life and the ability of people and societies to contribute to the world, supporting by the equitable distribution of resources, overall thriving and sustainability (WHO, 2021).

In line with the paradigm shift that traditionally associates the wellbeing to the economic growth and consumption, sustainable wellbeing can be effectively implemented since decoupling human wellbeing from resource progressive depletion is crucial to sustainability transition/transformation (IPCC, 2014).

Evidence confirm that welfare and wellbeing are feasible even with substantially reduced resource consumption (IPCC, 2014, 2022).

But it is crucial the introduction of the human component directly as criteria or as constraints in projects and processes with an environmental impact. Practices involved humans in a socio-eco-technical perspective need to be improving, and new production models based on circularity, large-scale and long-range view affirmed. Since beliefs determine attitudes and decisions, it is paramount working to sharing knowledge's and common values for a more conscious people about current interconnected needs for sustainable health and wellbeing (Lumbreras, 2021).

HFE approach can contribute to increase this awareness by highlighting the human component of the anthropic actions on the environment at the different stages, and its central role for a sustainable wellbeing.

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# Ergonomics for Sustainable Wellbeing

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Studies developed in the last years document a consolidated trend within Human Factors and Ergonomics (HFE) that affirms its a crucial role in promoting sustainable wellbeing by proposing a new generation of products, services, systems of solutions, and anthropic environments that harmonize with human and environment dimensions to propose more aware ways to use and consume the available resources (García-Acosta & Lange-Morales, 2019). Accordingly, sustainable wellbeing is a multifaceted concept that encompasses not only physical and mental health, but also environmental and social wellbeing (O’Mahony, 2022).

The pursuit of “good life” within the Earth’s carrying capacity is the goal of an holistic approach to wellbeing, and humans are currently called to act by adjusting to planetary limits, building physical and cognitive infrastructures, and operating models that respond to human needs within the framework of promoting sustainability (Hämäläinen, 2013)

From an HFE perspective, sustainable wellbeing can be achieved in many ways; for example, by designing workspaces and environments that promote comfort, efficiency, and reduced fatigue, but also by an-

ticipating human behaviours to propose pro-socially and pro-environmentally friendly attitudes.

Nowadays, the contribution of HFE in mitigating the environmental pressures, intended as the results of anthropic actions into urban, natural, and work environments is apparent. By prioritizing “good HFE” it is possible to reduce waste, conserve resources, and promote a culture of sustainability that benefits both individuals and the environment (Fischer et al., 2021).

As discussed in the Volume 27 of the *Rivista Italiana di Ergonomia* [Italian Journal of Ergonomics], there is a close tie between human features of the interactions with environmental resources, either anthropic or natural. The consumption of resources is a crucial driver of the anthropic pressure on the planet, highly connoting the human-environment relationships (Bălteanu & Dogaru, 2011).

Opinions, ideals, attitudes, habits, assumed lifestyles or even meaning systems projecting purpose on one’s own life have an impact on sustainability. HFE focuses on them by considering humans in a global perspective (Lumbreras et al., 2021).

Considering the design-driven dimension of HFE approach, along with conception of man-made objects, products, equipment, and environments that people use, and the provision of services and procedures to people, or performing work and other human activities, all including resources involvement (Hasanain, 2024), HFE can be considered as a medium to integrate Sustainability and Human Centered Design strategies, particularly in the question of resources (Demirel & Duffy, 2013)

In a sustainability perspective, this implies considering the human component in the environmental footprint, at all stages of the production of products, environment, or services’ process (Thomas et al., 2023). From conception to re-use, human and artefacts’ sustainable performance can be improved by adopting a lifecycle perspective to maximize the environmental, social, and economic benefits; thanks to a minimization of the associated social and environmental costs in production due to the optimizations of human-environment interactions.

The goals of decreasing materials quantities, waste and pollution upstream, also pursued through a circular design approach, are increased if usability requirements and affective qualities of artefacts are included in the sustainable design approach (Thatcher, 2012), since human centred design can foster sustainable behaviours going

beyond the idea that artefacts are consumable-goods, in favour of a paradigm shift based on durability in which the use value lasts as long as possible (Mesa et al., 2022).

To reinforce the scientific understanding around these topics, along with the progression of the scientific debates about positive ways of living and consuming the environments, the Volume 28 of the *Rivista Italiana di Ergonomia* [Italian Journal of Ergonomics] promotes a reflection on the strategic topic 'Ergonomics for a Sustainable Wellbeing'. This is done through a collection of works coming from different fields. Volume 28 intends to address the pressing need for innovative solutions and ways of rehousing the environments to tackle the complex issues of human-environment interaction under a sustainable perspective. Accordingly, the human side related to design interventions are critically assessed against environmental features to introduce initial discussion via novel interdisciplinary studies. Through this collection of scientific essays, the editors intend to stimulate a reflection on the role that HFE can play at different levels.

The Volume 28 provides continuity to the group of articles presented in Volume 27 and opens to a novel discussion path for the *Rivista Italiana di Ergonomia* [Italian Journal of Ergonomics]. Volume 28 intends to raise the quality of the scientific discussion around the emerging trends of HFE by proposing a fresh perspective through original viewpoints, which ultimately are expected to contribute to introduce novel perspectives toward the achievement of SDGs. Specifically, a collection of five high-quality works is proposed. These reflect on the multifaced sustainable qualities revolving around the concept of sustainable wellbeing in different testing grounds, from product design to mobility sector, till urban and work environments. By using different angles, selected works introduce original insights useful for theorists, researchers, and practitioners working in the HFE domain. Therefore, human-product interactions, new tools, regulations and policies, but also new product development and research methods are relevant topics covered by selected works.

Human wellbeing involves respecting public properties; this is the thesis behind the work of Sadeghi Naeini and Tabatabaee entitled "Vandalism prevention through ergonomic design: an approach on sustainability", which discusses the relationship between ergonomics, design for sustainability, and vandalism prevention. The work advocates the importance of considering ergonomics in product design to positively influence user behaviour and prevent vandalism with the

goal of promoting sustainable uses.

The work proposed by Viviani et al., entitled “Design for behaviour change to foster product longevity: a case study on sustainable mobility”, focuses on sustainable HCD interventions for behavioural change in the mobility sector. Their study emphasizes upcycling and longevity using a model to promote sustainable urban micro-mobility; strategies discussed by authors include the development of bike-to-e-bike conversion kits to support eco-friendly mobility solutions.

An interesting perspective on the theme of human wellbeing is provided by the work of Mastrolonardo and Nanni, entitled “Active times and public space: spatial devices and affordances for sharing urban space”, who discuss the importance of shared urban spaces by focusing on road sharing and vulnerable users in Italy. Authors emphasize the need for policy and behavioural improvements to promote sustainable urban mobility, reduce negative impacts of transport, and enhance the quality of urban life.

Signore et al. emphasize the importance of identifying stressors and promoting a supportive work environment to address work-related stress and absenteeism; in their work entitled “Health and safety executive indicator tool (HSE-IT) as a cognitive ergonomics management tool”. Authors used feedback recorded through a random sample of 2,134 workers to provide significant evidence that may contribute to achieving the sustainable development goals by enhancing mental health in the workplace.

The work of Del Gaudio, entitled “The energy cost of thermo-hygrometric comfort at the workplace” provides interesting insights on the importance of maintaining thermal comfort in the workplace, mainly referring to the Italian scenario. Del Gaudio underscores the importance of prioritizing thermal comfort in the workplace, complying with regulations, implementing energy-efficient practices, and aligning with global sustainability goals to create healthier – re: more productive – and environmentally friendly work environments.

Although the five contributions selected for the Volume 28 of the *Rivista Italiana di Ergonomia* [Italian Journal of Ergonomics] only depict a small part of the entire and much more complete scientific debate around ergonomics and sustainable wellbeing, the editors desire to provide a fresh angle to trigger innovative reflections as well as to open up future research avenues on this regards, which is consistent to the emerging perspectives about social, environmental, and economic sustainability.

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# Vandalism Prevention Through Ergonomic Design: An Approach on Sustainability



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Keywords: ergonomics, sustainability, vandalism, product

## Abstract

**This study recognizes the significant impact of ergonomics considerations and design for sustainability on product design. However, it also highlights a potential challenge, which is the issue of vandalism. Ergonomic design that prioritizes product beautification, or making the product aesthetically pleasing, can sometimes lead to users treating the product. This behaviour can result in vandalism, where users may intentionally damage or destroy the product. In this study 82 participants filled out the online questionnaires and mentioned their opinions about products and how use them. This research show that in the majority of cases, the ergonomic design for products are important for users in terms of the products treating and proper using the stuff. By making the product more intuitive and user-friendly, users may be more inclined to use it properly and prevent damage. Surely, ergonomic design based on vandalism prevention develop some sorts of benefits in terms of different aspects of sustainability especial social and economic factors.**

## Introduction

Vandalism is known as a problem which is related to economics, social and political problem (Kruzhkova et al., 2018), this behaviour includes some purposive actions for destroying street furniture, vehicle, assets, properties which belonging to a municipality or a person. Study of vandalism as a strategy of interaction in the information space of the city, assessment of economic damage from its consequences, identification of vulnerability zones for vandal manifestations is related to some kinds of different aspects i.e., psychological, sociological, cultural, and economics. In this regard, vandalism make some challenges for sustainability. Sustainable development is known as a global pledge toward quality of life for current and future communities. Therefore, multidisciplinary sciences which concern human beings and people life style play an important role in sustainability and achieving its goals. All main pillars of sustainability including economic, ecological, and social aspects are related to human life, in this regard the role of ergonomics in design for sustainability is crucial (Sadeghi Naeini, 2020; Sadeghi Naeini et al., 2022) both of ergonomics and sustainability concern productive and wealthy community (Attaianese & Rossi, 2023)

Besides, during last two decades an appropriate adopting between design and nature related considerations have been focusing and several sorts of design issues such as biomimicry design and product Life Cycle design are emphasizing (Vezzoli, 2022).

There are some different aspects in design for sustainability such as functional diversity, persistence, system efficiency, sense of identity, and adaptive capacity (Thatcher, 2022). Undoubtedly design for sustainability and taking into account the sustainability considerations in product design are so important, not only for customers, but also for producers.

Considering a significant lack of research on ergonomics and vandalism, the main aim of this work is overall assessment of relationship between ergonomics in design, and prevention of product vandalism. In fact, authors believe that Ergonomics can encourage users to take care of tools and use them properly.

## Vandalism

Destroying public property, making noise, disturbing others, and deviant customer behaviour are known as some vandalism samples

(Wu et al., 2020), however, the young people make Vandalism more than other groups (Lévy-Leboyer, 1984). As vandalism is known as a kind of crime and includes several different factors, the accurate data gathering about its roots is not easy (Buck et al., 2003), however, some kinds of related factors are introduced in some research such as city infrastructure, urban beatification, comfort of the urban structure, freedom of choice, citizens' behaviours, ecological barriers, motivators and meanings (Kruzhkova et al., 2018). Vandalism make some negative effects in terms of financial losses, art works destroying, reduced public services (Fuellgrabe, 1980), however, it doesn't limit to urban furniture and individual properties might be included, too. Figure 1 shows some samples (bins) of vandalism in Tehran public areas.



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*Figure 1. Some destroyed bins in urban place.*

Vandalism is a serious social, economic, and political problem that are known as modern society impacts (Kruzhkova et al., 2018). Undoubtedly vandalism makes social costs (Kruzhkova et al., 2018; Thompson et al., 2012; Wu et al., 2020). Resilience is a term that states the environment enable to suffer some effects and to return to a “normal” state (Thatcher, 2022), however, vandalism has some negative effect on this feature, too. All sorts of vandalisms make some negative effects in terms of urban sustainability, and as some of the vandalism’ causes might be inhibited by ergonomic design, in this regard, ergonomics interventions in street furniture not only decrease the vandalisms but also improve the urban sustainability.

## Ergonomics

Ergonomics has a wide scope in which sustainability, productivity, human being, work-related health and safety, workstation and product, system design and so on, are considered (Sadeghi Naeini, 2020; Sadeghi Naeini et al., 2022). All sub-branches of ergonomics i.e., environmental, social, cognitive, micro and macro ergonomics play prominent roles in people quality of life (Mosaddad et al., 2022), in this regard, ergonomics scope is not limited to industrial sectors. Ergonomics consideration might be done in everywhere from home and city to manufacturing systems. Furthermore, based on its features and as it is known as a human center multidisciplinary science, there is a firm association between ergonomics and sustainability (Sadeghi Naeini et al., 2023).

Ergonomic design not only is not an unaffordable luxury or an expensive action (Achim, 2014), but also it is able to decrease some costly crime based behaviour. In this paper, this characteristics of ergonomic design is focused. Ergonomic design in products decrease the fatigue and discomfort, in this regards, the mentioned characteristic might be effected on human behaviour and decrease the crime based actions.

Also, workplace violence makes some side effects on workers and employers, and according to WHO these behaviours define as “the intentional use of physical force or power, threatened or actual, against oneself, another person, or against a group or community, that either results in or has a high likelihood of resulting in injury, death, psychological harm, maldevelopment or deprivation” (Wang, 2008).

Ergonomics benefits supposed to make a preventive condition in decreasing the mentioned behaviours, however, the ergonomics reports have unnoticed the problems of workplace violence (Ju Kim, 2016). Un-

doubtedly, poor ergonomic-based violence is not limit to work places, it means, other environment such as urban areas might be effected by these behaviours. Furthermore, consumer ergonomics interventions in usability based product design is not limit to user satisfaction, and another characteristic such as user experience, aesthetics experience play a crucial role, in this regard, ergonomic design can change the user behaviour not only to use the product properly, but also to encourage the user to care the product (Sonderegger & Sauer, 2010). The mentioned characteristics might be made some behaviours against vandalism, for instance, ergonomic convince of urban places is one of the strategy to control vandals (Kruzhkova et al., 2018).

### Method

In this case study, a questionnaire was designed to gather the opinions of participants regarding the role of ergonomics in describing vandalism and violent behaviors. The questionnaire was distributed to industrial design students via Google Form through social network links, and 82 participants volunteered to fill it out. To collect data, pairs of street furniture and hand tools (Fig.2) were selected to gauge the participants' perceptions of their design. To further elucidate the impact of good design on reducing vandalism, interviews were conducted and products were selected in pairs for comparison in terms of potential vandalism during their use. Participants in the mentioned interview were some of experienced scholars and experts in industrial design. In each pair of pictures, participants were asked to choose

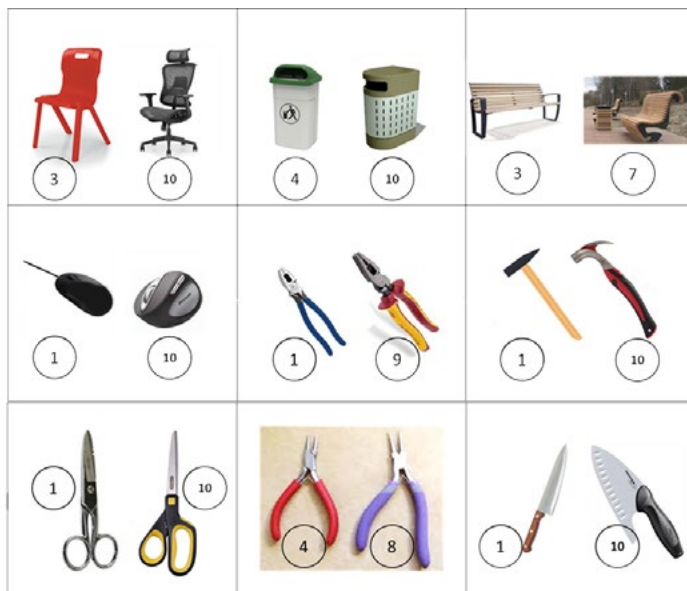


Figure 2. Significant of proper usage of pair products (Scores out of 10).

the item they believed was less likely to be vandalized.

## Results

As Figure 2 shows, in most cases, people tend to prefer and prioritize products that not only meet their functional needs but also have appealing aesthetics, which is a combination of ergonomics and design principles. This preference is commonly observed in various products such as office stuffs, hand tools, utensils, and urban furniture. Consider the gathered data, the effects of ergonomics considerations and aesthetics to use the products in the proper and appropriate way is noticeable in some daily used products. The scores in the figure 2 which were found in the filled out the questionnaires are out of 10. All of the interviewed participants confirmed that ergonomic design as a special aspects of good design, and aesthetics as a general product design aspects encourage the users to care about products. Figure 3 displays two types of public bus seats, with noticeable differences in vandalism between them. Specifically, seat (a) seems more appealing



*Figure 3. Comparison of two different bus seats in terms of vandalism signs (Authors).*

and shows no signs of vandalism compared to seat (b).

## Discussion and Conclusion

The present study aimed to assess the effects of ergonomics in product design on vandalism prevention. Prevention of product-based vandalism is also associated all aspects of sustainability.

The importance of sustainability is a fact and holding some sorts of international meetings (i.e. UN Conference on the Human Environment-Stockholm Conference-, Sweden, June 5-16, 1972; UN World

Commission on Environment and Development 1987 with slogan of Our Common Future; UN Conference on Environment and Development in Rio de Janeiro, 3-14 June 1992; UN Conference entitled Earth Summit +5, New York, 23-27 June 1997; UN Millennium Summit (2000), UN-World Summit on Sustainable Development- Johannesburg Summit, South Africa, 26 August - 4 September 2002; UN Conference on Sustainable Development "Rio + 20" in 2012 (20-22 June); UN-International Conference on Small Island Developing States, 1 - 4 September 2014, Apia, Samoa; UN Sustainable Development Summit, 25 - 27 September 2015, New York, and UN Sustainable Development Summit (2015) in which Agenda 2030 including 17 Sustainable Development Goals was introduced) confirms the importance of sustainable development. In this regard the multidisciplinary science which concern human being such as Ergonomics should be considered by designers, industrial sectors authorities and so on. Undoubtedly, ergonomic products make a better condition for users. Furthermore, based on the gathered data and result analysis, it becomes evident that product features, aesthetics, and ergonomics play a crucial role in shaping the user's experience and their opinions about the product. Users tend to give more attention to the usage and maintenance of ergonomic products compared to other similar products.

Considering the interviewed experts' opinion, and assessed the questionnaires, people, more or less, respect to good design, and ergonomic products, so they care about these products; The mentioned opinion means a behaviour against vandalism, however, more research need for validation of this idea.

As depicted in Figure 2, proper utilization and care of products recognized for their ergonomic qualities hold significant importance for users. Considering the gathered data, it seems that product design based on ergonomics consideration and aesthetics persuade users to use the products in proper way, consequently, these sorts of design make some positive effects in the process of design for sustainability. Undoubtedly, and as above-mentioned to explore how the mentioned characteristics in designed product are going to change the users' behaviours to care the products, need more research. This small scale study more or less showed a relationship between the mentioned features, it means more attention to ergonomics intervention in product design and developing some products based on aesthetics will be ended to some products which are used properly. Surely, this condition effects on product's longevity then decreasing waste and vandalisms.

Product satisfaction depends on user and a product's interface communication in which some kinds of factors are involved i.e. aesthetics, usability, color (Alves et al., 2022). Also, aesthetics characteristics of products play prominent role in product and systems design (Sonderregger & Sauer, 2010). Searching in Scopus confirms that there is no articles title includes the both words of ergonomics and vandalism. It shows a deep lack of documents in the mentioned field, therefore, authors highly recommend to conduct more research about the role of aesthetics and ergonomic design in decreasing of vandalism, and study about anti-vandalism design for future studies.

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# Design for behaviour change to foster product longevity: a case study on sustainable mobility



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Keywords: design for behaviour change, sustainable mobility, light-vehicle design, design for longevity, user engagement, technology acceptance.

## Abstract

**This article focuses on the role of product-service system design as a driver to guide and motivate behaviours for active and sustainable mobility. The article refers to the systemic link between microergonomics and sustainable development and addresses how the concept of behavioural change fits into the relationship between human and environmental aspects. The research domain encompasses sustainable urban mobility. The aim is to identify inquiry directions for product-service system design solutions to be consistent with environmental sustainability goals. Behaviours related to sustainable mobility and factors influencing modal choice have been analysed. Finally, through developing a design concept, the article discusses and defines new design opportunities at the**

**micro level of the urban scale stimulating the adoption of desirable mobility behaviours over existing ones. The developed case study fuels the debate on the effectiveness of ergonomic interventions to better use and consumption of resources, implementing the vision of the tools and processes to be adopted in defining reusable product-service systems with low environmental impact.**

## Introduction

Chavez et al. (2022) inquire into the environmental impact of user actions during product usage and reuse phases and assert that focusing Ergonomics and Human Factors objectives solely for anthropocentric benefit is restrictive. Therefore, they delve into and visualize the relationship between micro-ergonomics (micro-systemic), macro-ergonomics approach (meso-systemic) and Design for Sustainable Development (macro-systemic). The ergonomics-ecodesign link identified in the use phase of the Life Cycle of the System Product (see Vezzoli & Manzini, 2008) gives rise to new areas of ergonomic experimentation characterized by eco-friendly aspects. In particular, this article focuses on the reuse phase, i.e. the design model "design for longevity" (see RSA, 2013), as i) a key factor to minimise negative environmental impacts in the context of sustainable mobility; and ii) a behavioural attitude to be observed to extend the lifespan of products, in line with the preferences of the reference users.

In the debate about sustainability, the literature suggests that the design of ergonomic interventions should entail a further exploration of additional interdisciplinary, design-oriented contributions. Indeed, Piscicelli and Ludden (2016) introduce Design for Behaviour Change as a methodological approach applicable to the circular economy context to understand user behaviour, guide user choice "towards circular business models" and foster acceptance of disruptive products characterised by sustainability values. In the framework of 'Design for Behaviour Change', Clune (2010) argues that endorsing environmental sustainability objectives entails more than just developing new solutions, it also stimulates the user towards the adoption of desirable 'behaviours' for existing solutions. Sadeghian et al. (2022) argue that technical efficiency must be accompanied by a broader holistic perspective, where sustainability is a clear overarching goal, and technology design considers: i) what stage of behavioural change do users position themselves; ii) what opinions they hold regarding sustainable mobility; iii) what factors influence

their intentions. To harness the advantages of emerging technologies (such as electric vehicles, automation, micromobility, and shared mobility), lifestyle and behavioural changes should precede the proposal of innovative transportation solutions, particularly in the context of individual mobility practices.

Holden et al. (2020) point out the need to act on human values towards the environment and patterns of behaviour and consumption. Related to this, Sadeghian et. al. (2022) identify and analyse factors influencing people's mobility behaviour choices to help instil change through the vector of 'technology design'. Attaianese and Rossi (2023) assert the Human Centred Design (HCD) approach correlates and converges Human Factors and Ergonomics (HFE) techniques in the definition of sustainable design scenarios. They delved into the possible explorations of sustainable HCD to define new scenarios linking HFE and sustainability useful to frame new research paths. Chavez et. al. (2022) broadened product vision from an individual entity to a 'sustainable product-service system' (SPSS). Attaianese and Rossi (2023) indirectly support these statements. They point out that the holistic interaction between human behaviour, creative design practices, and the sustainable quality of contexts of use (International Ergonomics Association, 2022) extends from the micro to the macro level. In other words, they assert that HCD visions and strategies can define sustainable interventions at the human scale, addressing behaviours and well-being ones, proper to the HFE. Therefore, they are capable of supporting relevant macro-themes posed by the sustainability domain.

The connection between the product and the macro-systemic level can be supported by good practices assessing: i) the environmental impact and effects of the product, such as Design for Environment, Ecodesign, and Product Life Cycle; ii) the ergonomic aspects of the product, such as Inclusive Design, "design adjustable", Universal Design and Specialised Design; iii) the user acceptance and perception concerning the use of the product (Chavez et al., 2022). Regarding the third point, this paper proposes to integrate insights from behavioural sciences into the HCD process. It means integrating some steps of the "Design for Behaviour Change" methodological approach as a good practice to foster social acceptance of reuse products in the sustainable mobility field. Therefore, the study presented in this paper explores the potential contribution of sustainable HCD at the 'product-service system innovation (PSS)' level. It proposes the in-

tegration of HCD methodologies and HFE knowledge in the field of Design for Behaviour change for sustainability (cf. Attaianese and Rossi, 2023).

## **Factors influencing sustainable mobility choices**

Climate change highlights the urgency and imperative to adopt new behavioural habits, especially in the sustainable urban mobility field (Intergovernmental Panel on Climate Change, 2022). The shift in lifestyles and behavioural attitudes is fundamental to innovative design actions that integrate sustainability objectives and steer individuals in the use and reuse of products. Design for Behaviour Change is a field of design research and practice that focuses on human behaviour, through social and behavioural science theories, and studies how design can change behaviours (Ceschin, F., & Gaziulusoy, İ. 2019; Niedderer, et al. 2017; Piscicelli, L. & Ludden, G. 2016; Wever, R., 2012). In the context of upcycling research, Sung et al. (2022) conducted a research project in the UK to scale up upcycling, both in households and businesses. The results highlighted the effectiveness of adopting Darnton's Nine Principles (see Darnton, 2008) as a framework for understanding and defining behavioural intervention strategies. Concerning the HCD process, the two phases and related steps of the above-mentioned framework can support and implement the 'user research' phase through i) identifying the behavioural model for exploration; ii) understanding consumer behaviour; iii) refining the behaviour model for operationalisation; iv) identify key drivers, facilitators and barriers (Sung et al., 2022).

In support of the sustainable urban mobility research domain, Sadeghian et al. (2022) propose integrating the Theory of Planned Behaviour (TPB) and Prochaska's Transtheoretical Model of Behaviour Change (cf. Prochaska et al., 2015) to identify factors influencing behavioural change across various stages of user transition. In their conclusions, Sadeghian et al. (2022) categorize factors supporting sustainable mobility objectives into components of behavioural intention (see Tab. 1).

Factors influencing user mobility choices analysis highlight the individual needs to address and guide opportunities for design improvement, including interventions that promote acceptance of new mobility technologies and product-service systems. Sung K. (2017) lays the foundations for exploring target users' behavioural intentions by

re-evaluating factors derived from methods such as literature reviews, semi-structured interviews, questionnaires, and online surveys. Building on Sung et al.'s (2022) framework, these methods aid the final phase of "developing interventions" and its corresponding steps which are: i) designing promising interventions and ii) evaluating and refining the draft interventions.

*Table 1. Factors influencing sustainable mobility choices.*

<b>Components of behavioral intention</b>	<b>Factors influencing mobility choices</b>
<b>Affective attitude</b>	Joy of driving
	Product attractiveness
	Support for local industries
	Rejection of climate change
<b>Instrumental attitude</b>	Comfort
	Safety
	Costs
	Time efficiency
<b>Descriptive norms</b>	Status symbol
	Social values
	Personal values
	Social norms
	Personal norms
<b>Control beliefs</b>	Access to services and infrastructure
	Desire for green energy and eco-friendly driving
<b>Perceived Behavioral Control</b>	Trade-offs
	Radical approaches, such as political or legislative actions

The study presented in the subsequent chapter initiates a discourse on potential technological and design opportunities.

## **Methodological approach**

This study is based on a design experimentation that relies on employing a practice-oriented research strategy that offers enhanced insight into complex, future-oriented issues: research through design (cf. Godin and Zahedi, 2014). The overarching objective of the design research process addressed in this study is to foster the acceptance of new, more sustainable individual mobility technological perspec-

tives through the proposition of an electric bike conversion kit. Specifically, the concept of upcycling within the sustainable urban mobility field was explored to enhance the longevity and desirability of human-powered bicycles. The solution entailed maximizing material utilization through the definition of an easily applicable artefact that renews existing micromobility solutions, meeting the needs of personal mobility.

Methodologically, this study adopts an HCD approach. In parallel, the design innovation process is founded on a design-oriented model integrating theoretical elements derived from behavioural and social sciences into the design process. In other words, the "Double-Diamond-one-dot process model for behaviour change interventions" (DDfBC), as proposed by Van Essen et al. (2016), has been adopted. The design experimentation unfolds in three stages: discover, define, develop/deliver.

The research activities included HCD evaluation methods and were structured into design steps within the framework proposed by Sung et al. (2022), as described in Table 2. The development of the first research phase (discover) focussed on target users' needs, requirements, and behavioural intentions to introduce technological, sustainable, and human-centered innovations based on parameters from social and behavioural sciences. In this phase, literature review, stakeholder identification, and focus groups were performed. Users were categorized based on Prochaska's "Transtheoretical Model of Behaviour Change" and framed as "users in the contemplation stage" (cf. Prochaska J. et al., 2015). The preparation of the two focus group events involved organizing literature data into semi-structured interviews, starting from the influencing factors of mobility choices, and investigating the main modes of transportation and key determinants that could motivate healthier, more aware, and sustainable lifestyles. The results of the first research stage converge and lay the foundations for the development of the second design phase (define). During the "designing promising interventions" (Darnton, 2008) design step, analysis and collection of results from previously conducted research was carried out. It led to the identification of the present design vector: a bike-to-e-bike conversion kit. The following phases have been made to identify the bike-to-e-bike kit: i) analysis of the state-of-the-art products on the market; ii) selection of product type; iii) breakdown of the hierarchical sequence of actions that the user performs in in-

stalling the conversion kit onto the bicycle; and iv) understanding the product usage modes. Therefore, three methods, "benchmarking" "hierarchical task analysis" and "applied ethnography", were structured to understand and categorize the set of actions that users perform in interacting with and/or installing the product. These activities led to the identification of a strategic brief prepared to systematically arrange the emerged objectives (cf. Rinaldi et al., 2020). The third research phase (develop/deliver) explored various types of creative and innovative solutions to diversify the bike-to-e-bike conversion kit as a key product of the design process. The objective was to outline the broad vision associated with sustainability goals. This converges in the development of a design concept, a synthesis of the conducted research, through the use of 3D modeling and rendering software.

Table 2. Research activities planning.

Stages		Phases	Steps <small>(cfr. Sung et al. 2022)</small>	Methods
DDfBC	HCD			
Discover	User research	Understand and specify the context of use	Identify behaviour model for exploration	Literature review
			Understand consumer behaviour	Identify stakeholder
				Focus group
			Refine the behaviour model for operationalisation	Literature review
Identify key drivers, facilitators and barriers	Focus group			
Define	User research	Defining the requirements of the design	Designing promising interventions	Secondary research <b>Identification of the behavioral change vector</b>
			Specify the user requirements	Benchmarking
				Hierarchical task analysis Applied ethnography
<b>"Design pressure cooker"</b>			<b>Definition of the strategic brief</b>	
Develop/deliver	Design solution	Produce design solutions to meet requirements	Evaluate and improve the draft interventions	Brainstorming
		Evaluate the designs against requirements		Idea generation Visual prototyping

## Results: a case study of an electric bike conversion kit

As a result, the emerging design proposal is an electric conversion kit for bicycles enhancing the product's lifecycle and includes formal, technical, functional, and systemic innovations regarding: i) ease of use and pleasantness; ii) product engineering; and iii) the definition of engagement strategies through post-purchase services.

The target audience is individuals who are aware of environmental issues and are undergoing a transition towards more sustainable personal mobility actions. From the focus groups, there was significant interest in nudge solutions that support positive social relationships to reduce high levels of work-related stress and technologies that meet green mobility needs, with zero environmental impact, extending the life of their personal bicycles.

From the secondary research (as a result of the first stage of the Double Diamond process), the analysis conducted by Sadeghian et al. (2022) led the research to identify three inputs for the design process: i) meeting individual needs and shaping positive experiences; ii) guiding individuals by providing information on available opportunities and the impact of individual and collective behaviours; iii) being salient in social contexts and allowing connection to peers. Gabrielli et al. (2014) outline a guide to support the development of future mobility solutions and highlight inputs conducive to designing persuasive means, which align with the former inputs. These include: i) creating collective challenges shared at the local level; ii) designing solutions that provide feedback to users regarding their mobility choices and environmental impacts; and iii) supporting mechanisms of social influence. Similarly, Klecha and Gianni (2018) identified how technology can facilitate the behavioural change process by: i) designing persuasive solutions accessible from mobile devices; ii) defining persuasive strategies to facilitate access to mobility information, personalize data, and enable self-monitoring; iii) designing co-design and participatory laboratory activities to involve users in the process phases.

In this research phase, electric bike conversion kits were selected as a design opportunity to further support project objectives. The results of the activities in the first two stages of research converge towards identifying the best solution to implement and prototype. To support the development of the third research phase (develop/

deliver), a technical document was prepared to synthetically and systematically frame the design requirements for defining an output oriented towards change (refer to Table 3).

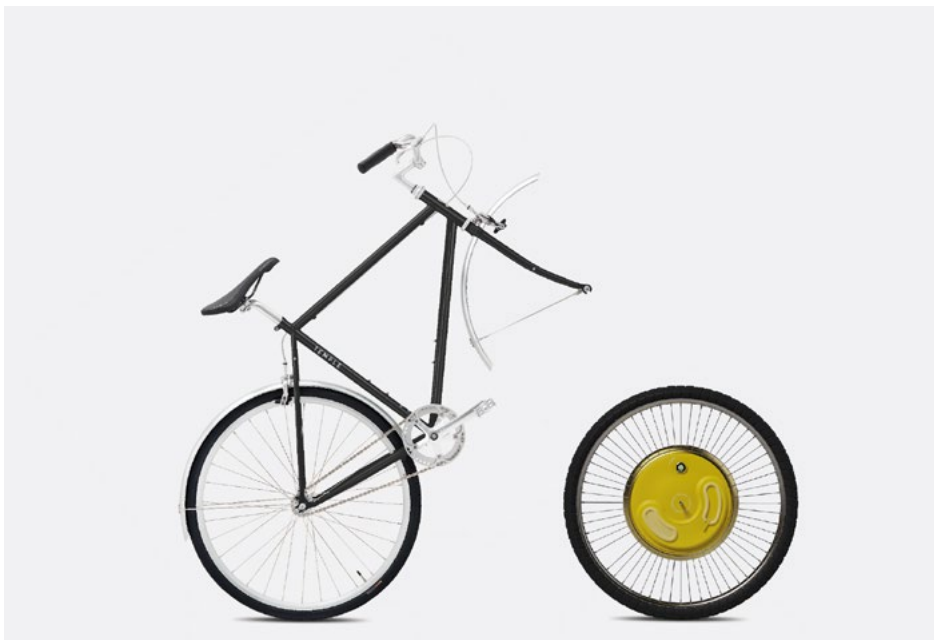
*Table 3. Strategic brief to foster technological, sustainability and human-centred innovations within the parameters of the social and behavioural sciences.*

Strategic brief		
<i>R1</i>	Designing the <b>technological acceptability</b> of the product-service system	
<i>R2</i>	Designing a product <b>extending the life cycle of existing mobility solutions</b> , supporting 'design for longevity'	
<i>R3</i>	Designing for a <b>target group in the 'contemplation' phase</b> (cf. Sadeghian et. al., 2022), i.e. aware of the environmental problem and intending to change their mobility choices	
<i>R4.1</i>	Designing a <b>product-service system motivating the behavioural change process:</b>	solutions characterised by ease of use and agile applicability
<i>R4.2</i>		compact, all-in-one solutions characterised by modularity
<i>R4.3</i>		persuasive solutions exploiting the potential of mobile devices
<i>R4.4</i>		collective challenges, shared at the local level or by shaping positive experiences and creating social influence mechanisms
<i>R4.5</i>		data accessibility on the environmental impacts of users' individual and collective mobility choices
<i>R4.6</i>		informing about available modal opportunities
<i>R4.7</i>		codesign workshops and participatory design activities, for user involvement in the final stages of the process.

In order to increase user-friendliness and ease of use, the design proposal aims to favour the use of the bicycle and increase its attractiveness for last-mile commuting through the installation of a light, all-in-one, modular component that i) can be applied to any commercially available bicycle; ii) is an attribute of the micro-vehicle; and iii) improves the user experience. Product engineering includes analysing the design constraints, i.e. the minimum components required to make up the kit, the maximum overall dimensions between the fork and the wheel, and the positioning point for the effective extraction of the removable battery modules. Before the definition of the engagement strategies, the design choices concern: i) the minimum adaptability of the kit on bicycles with 20-inch wheels (see Figure 1); ii) the positioning of the kit on the front wheel, which facilitates assembly by the user without the need for an installer (see Figure 2); and iii) the removable and modular battery pack to allow the bike to be recharged without having to carry it all the way home or to the office (see Figure 3).



*Figure 1. The conversion kit is compatible with bicycles ranging from 20 to 29 inches in size.  
Design by Michele Marco Tizza - IDEE Lab.*



*Figure 2. Assembly system of the electric conversion kit. Design by Michele Marco Tizza -  
IDEE Lab.*

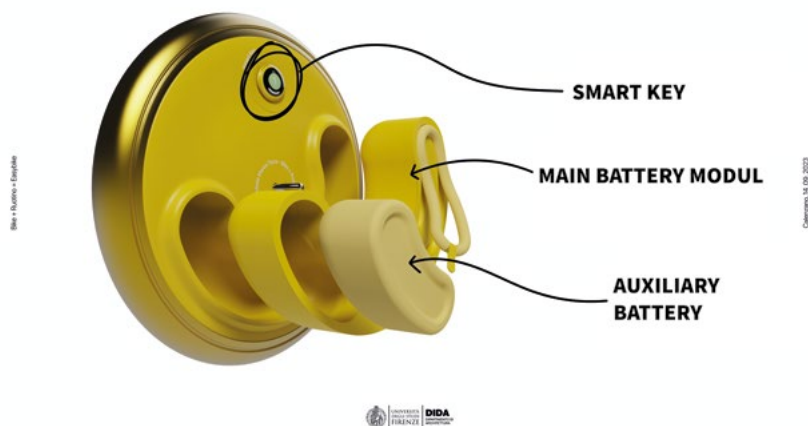


Figure 3. The electric conversion kit consists of two modular, removable battery packs. Design by Michele Marco Tizza - IDEE Lab.

The smart key, illustrated in Figure 3, acts as a bridge between of-line and online engagement services. Its user interface serves three functions: i) it displays the battery charge status; ii) encourages vehicle usage through attractive daily notifications; and iii) provides the user with information on personal statistics regarding environmental, health, and sports goals (refer to Fig. 4).



Figure 4. Smart key user interface. Design by Michele Marco Tizza - IDEE Lab.

Finally, the mobile app supporting the product system shapes positive socialisation experiences through collective challenges. These persuasive strategies activate gamification processes through nudges - including challenges between players, challenges with the community and challenges with oneself - and the reward system (see Figure 5).



Figure 5. Mobile app linked to the conversion kit with collective challenges at local level, for user engagement. Design by Michele Marco Tizza - IDEE Lab.

## Conclusions

The paper focused on understanding how designing sustainable product-service system that can facilitate the transition towards a circular economy. Consequently, this study fosters the debate about integrating behavioural and social sciences theories, ergonomic factors, environmental considerations, and eco-compatibility in a unique framework. The aim is to improve the utilization and consumption of existing technological solutions. The findings suggest the interplay between microergonomics and Design for Sustainable Development, specifically at the macro-systemic level, by: i) implementing processes for shaping product-service systems that are socially acceptable, reusable, and environmentally low-impact (Van

Essen et al., 2016); and ii) delineating new project objectives concerning behavioural change (Sung et al., 2022) in support of sustainable and active mobility.

The "Double-Diamond-one-dot process model for behaviour change interventions" (Van Essen et al. 2016) has been adopted as a design model to introduce and correlate the conceptual framework of "Design for behaviour change" with theoretical support tools that assess environmental effects and ergonomic aspects.

Within the practice-oriented process, following the design steps of Darnton's Nine Principles framework for behaviour change (Sung et al., 2022), target users and motivational strategies for adopting desirable behaviours have been identified through secondary research on factors influencing modal choices.

The results related to the design of a product-service system support the concept of "design for longevity" (see RSA, 2013) in the context of sustainable urban micro-mobility and propose a solution that responds to the inputs identified during the initial research phase, aimed at motivating a change in mobility patterns.

Finally, the results lay the groundwork for future work to be focussed on stakeholder engagement regarding the evaluation phase through co-design laboratory activities and participatory design activities aimed at finding behaviour interventions.

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# Active times and public space: spatial devices and affordances for sharing urban space



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Keywords: Climate change, Urban mobility, Public spaces, Road sharing, Vulnerable road users, Urban affordances

## **Abstract**

Road transport in the urban mobility sector plays a significant role in increasing fuel consumption, greenhouse gas (GHG) emissions and poor air quality. Understanding the relationship between the people and the public road environment is essential to ensure the well-being and safety of individuals and to mitigate the climate change impacts of urban mobility. The concept of shared urban space, with a particular focus on the street as a public space, is analysed, also considering policy, normative and behavioural improvements in Italy. It stresses the importance of awareness regarding energy and CO<sub>2</sub> savings by slowing down the space used by cars. The article looks at key spatial devices and opportunities that allow vulnerable road users such as pedestrians, cyclists, and motorcyclists to share the road effectively and safely. By treating streets as public spaces with multiple functions and uses, cities can unlock their potential as safe, accessible, and economically

**sustainable places. The article draws on theories of affordances, the spatial and temporal characterisation of activity in public spaces, and the role of traffic control devices in managing road sharing.**

### Introduction

Sustainable mobility planning in urban contexts is a multifaceted task that requires a comprehensive approach to address issues such as traffic congestion, air quality, and urban space utilization. Additionally, it involves the reconfiguration of public spaces and consideration of the psychology of the street (Mastrolonardo, 2021). Throughout the past century, roads worldwide have been constructed with a focus on accommodating cars. In many parts of the world, wide lanes and limited space for pedestrians have become the norm, resulting in divided cities, hindered economic growth, and hazardous traffic. To address this issue of sustainable mobility, a comprehensive approach that prioritises people is necessary. This involves transforming streets into safe, appealing, and economically thriving areas (Natto, 2016). As cities are increasingly recognised as places for people, the focus of urban design is shifting from prioritising the flow of vehicular traffic to understanding the needs of all users, including pedestrians, cyclists, and public transport users. This change in viewpoint is motivated by the increasing recognition that streets are not simply channels for vehicles, but instead are important public spaces that have a significant impact on the liveability, vibrancy, and sustainability of cities, particularly through reduced travel times that ensure greater safety for all and promote active mobility (UN-HABITAT, 2015) [Figure 1].

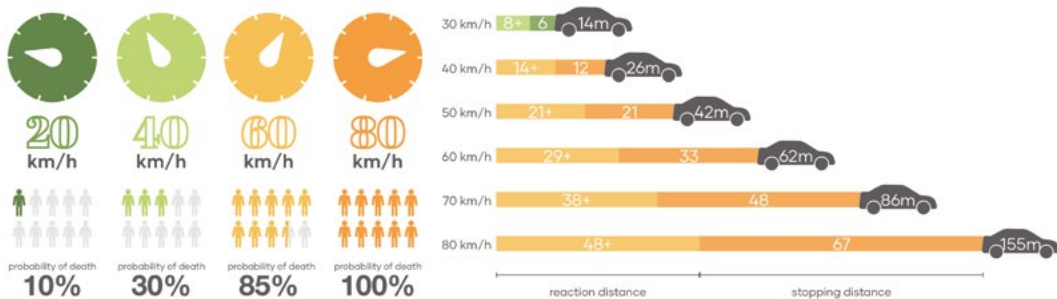


Figure 1. Probability of death related to increased speed.

A focus on accessibility, road safety and the redesign of public spaces is essential to achieve sustainable urban mobility planning (Tiboni, 2021). This requires a shift towards a more integrated approach to spatial and transport planning, emphasising the role of urban form and functionality (Un-Habitat, 2015). Design plays a crucial role in promoting sustainable urban mobility by rethinking street as public spaces, reducing the negative impacts of transport and provide accessible routes for all users for promoting mutual respect and road safety.

### **Spatial devices for sharing the road**

In urban areas, promoting road safety requires adopting a philosophy of spatial integration rather than a segregative model that restricts pedestrians and cyclists to minimal designated lanes. To achieve this, it is necessary to strategically reduce vehicle speeds in certain zones by implementing a soft functional road layout. This approach encourages the sharing of public space and includes traffic calming solutions. These technical solutions should be reconceptualised as spatial interventions. Signs, signals, road markings, and barriers function as crucial spatial devices, guiding and directing drivers to heighten their awareness of vulnerable road users and delineating expected behaviour within the shared urban landscape. Viewing traffic management as a nuanced spatial design challenge can promote safety and efficiency in the urban environment.

It is not a new idea that the strict separation of flows may not always be the optimal solution. This is supported by a decade-long study (1993-2003) conducted by Barbara Egger and Oskar Balsiger in Bern (2004) on the accident rate of cycle lanes at intersections. It can be argued that segregated systems in densely populated urban areas pose a greater risk to vulnerable users. In this case, the negative effects of reduced cyclist visibility outweigh the positive effects of physical protection [Figure 2]. To distinguish between two fundamental types of users, it can be useful to associate the concept of 'separation' with that of 'preference'. The first type is the slow pedestrian or cyclist user (child/elderly/non-expert) who requires an element of division if the gap between his travel speed and that of the vehicles is too great. The second type is the fast (expert) cyclist, often seen in commuters travelling to and from work. For this group, any element of separation can only hinder their need to travel quickly. When planning for slow

mobility in cities, it is important to consider these factors and give importance to every constituent element of open space, paying particular attention to intersections. The aim is to ensure priority and safe passage for the most vulnerable users, who have so far been overlooked in the design of routes throughout the modern city (Bambò Naya, 2023) [Figure 3].

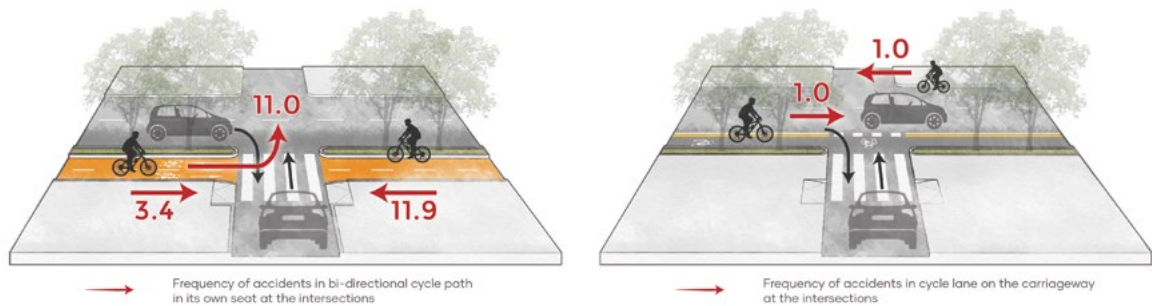


Figure 2. Road safety study: sharing space increases safety for weak users.

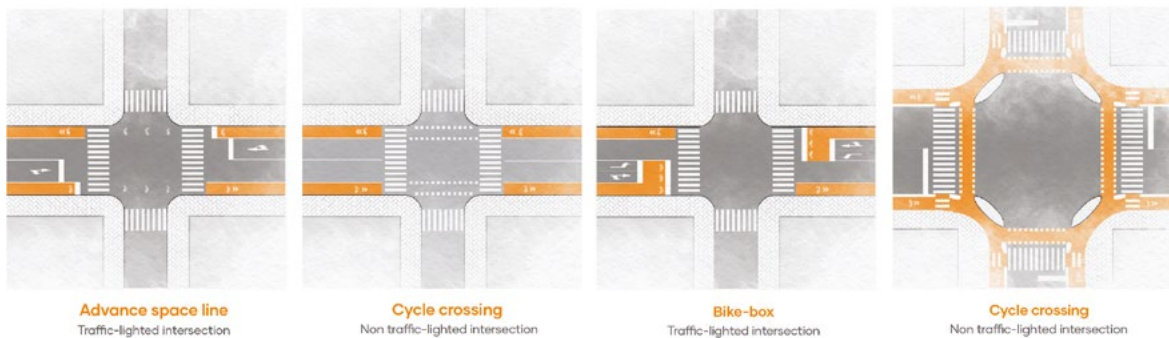


Figure 3. Priority for cyclists and continuity of cycle paths.

In Italy, progress has been made in promoting shared roadways, particularly for bicycles and slow mobility. This was reinforced by the post-COVID Decree (DL 76/2020), which introduced new tools into the Highway Code, previously focused solely on cars. The decree emphasised the importance of horizontal signs to facilitate sharing of the road. It also allowed for the reservation of spaces for slow mobility in cases where the road section is not large enough to accommodate infrastructure on its own site. Cycle lanes, one-way cycling, urban streets with cycle priority and sharing between bicycles and local public transport vehicles in the lanes reserved for the latter have been introduced [Figure 4].

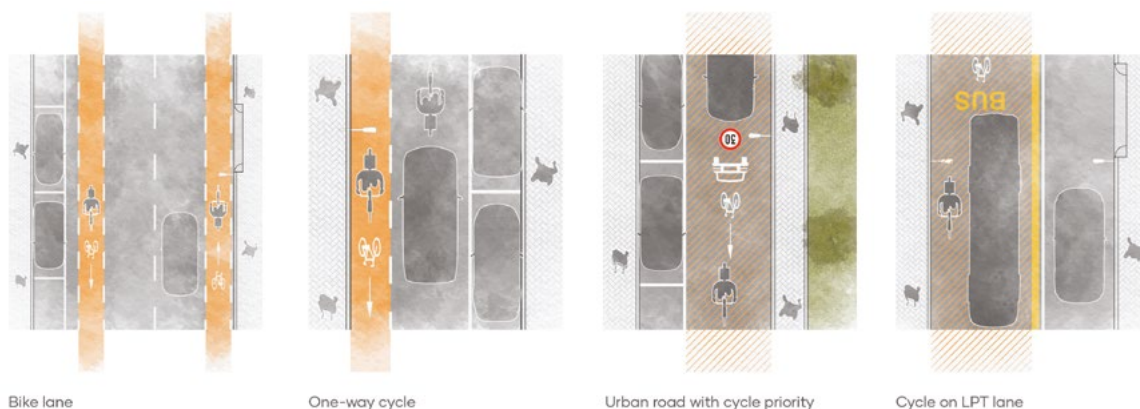


Figure 4. New sharing modes introduced by DL 76/2020.

The intervention possibilities introduced are feasible as long as they fall within moderate traffic areas with a speed of less than 30 km/h. These areas include environmental islands, residential areas, traffic-restricted zones, pedestrian areas, and 30 zones, which should represent the majority in urban areas (Swanson, 2020). The 'environmental islands' are areas within the main road network that aim to improve the quality of life through defined traffic calming measures. The three main regulatory documents that concern them are the Highway Code (DM 557/99), the Guidelines for the drafting of urban road safety plans (Circular no. 3698 of 06/08/2001), and Functional and Geometric for the Construction of Road Intersections (DM 19 April 2006). The solutions identified are presented below, integrated

with what is reported in the Global Street Design Guide (2016) and in the Handbook on Sustainable Urban Mobility and Spatial Planning

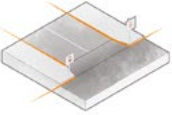
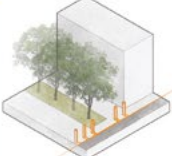

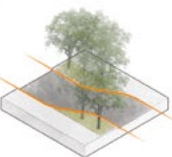
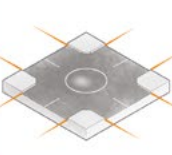
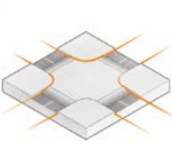

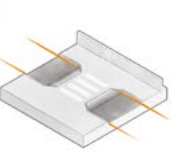
	Technical device	Spatial device	Anthropic features	Environmental features
access gate		The entrance from a main urban road to a moderate traffic area is marked to create a <b>clear visual and physical demarcation</b> . The new accessible space is characterised by a <b>different road language</b> .	The access gate is a clear sign of a <b>priority area for pedestrians and cyclists</b> . This allows the most vulnerable users to feel prioritised in their routes and access to public spaces.	The emphasis on the visual threshold is achieved by altering the surface texture and incorporating trees, signs, lighting, and bollards. Moreover, the accessed area has <b>better air quality and lower levels of noise pollution</b> .
traffic closure		Whether total or partial, it is generally planned within built-up areas. The aim is to create <b>new cycling and pedestrian spaces around major urban attractors</b> .	The closure of traffic allows <b>citizens to reclaim spaces</b> that belong to them, giving <b>renewed livability</b> to the areas of interest.	It is a solution that enables the reduction of <b>congestion</b> , improvement of <b>air quality</b> , reduction of <b>noise pollution</b> , and promotion of <b>accessibility</b> to various urban functions.
widened gap		It allows space to be reclaimed, transforming junctions into <b>small squares</b> with little distinction between sidewalk and road. This approach also offers opportunities for experimentation in the field of <b>tactical urbanism</b> .	A <b>larger pedestrian area</b> available <b>decreases the crossing distance and danger</b> for weaker users. This allows pedestrians to occupy a space that is often taken up by illegal parking.	The expansion can occur by increasing the <b>paved or permeable surface</b> available to users. Thus, the device also presents an opportunity for <b>de-paving interventions</b> .
chicane		The road axis features an <b>S-shaped deviation</b> without reducing the width or number of lanes. Additionally, <b>new shared spaces</b> will be created with priority given to the most vulnerable users.	The design of the new road discourages motorists from using it, <b>prioritising instead the safety and mobility of pedestrians and cyclists</b> .	Its realisation requires the creation of <b>new green spaces</b> that define the boundaries within which vehicles can operate. Improving <b>air quality and the surrounding environment</b> are key factors.
mini roundabout		The traffic circle is located at the <b>center of the intersections</b> and can have <b>variable dimensions</b> . It may be elevated above street level to varying degrees, making it partially or fully surmountable.	The geometry of the device improves <b>safety for pedestrian and cycle crossings</b> by imposing trajectory variation on vehicles. Furthermore, it enhances the <b>perception of space</b> for weaker users.	If there is sufficient space for a surmountable roundabout, it can be <b>vegetated</b> and, with the appropriate slope, can help <b>absorb rainwater</b> .
raised intersection		This is an <b>elevated space</b> that covers the entire intersection, characterized by a <b>different color or material</b> . Ramps connect to the roadway, slowing down vehicles.	Eliminating the height difference between the roadway and the sidewalk ensures a <b>continuous network for cycling and walking</b> , while also removing architectural barriers.	The type of pavement used can affect the behaviour of drivers, potentially deterring them from travelling through certain urban areas and leading to a <b>reduction in carbon emissions</b> .
lane restriction		It concerns the lanes on the outer side of the carriageway and may take the form of: <b>widening the sidewalk</b> on one or both sides of the road, interposing a <b>traffic island</b> between the lanes, and introducing side <b>flower beds</b> .	In most cases, pedestrian crossings are where they are created. <b>Reducing the crossing distance</b> can increase the <b>safety</b> of vulnerable users. It can also encourage them to cross more confidently.	When the carriageway is narrowed by the introduction of traffic islands or side flower beds, the <b>environmental performance</b> of the road and the provision of <b>permeable spaces</b> is improved.
raised crossing		It creates a <b>new uninterrupted space</b> within the network of pedestrian and cycle paths. This reduces the crossing distance and creates a car-free area for gathering.	The device enhances the <b>visibility</b> of road users, promoting pedestrian safety by <b>eliminating architectural barriers</b> and the height difference between the sidewalk and the driveway.	The crossing's raised provides an opportunity to <b>re-design the road section</b> . This can be achieved by adding <b>vegetation</b> in the immediate vicinity and further highlighting the presence of the device.

Figure 5. Matrix of traffic calming measures.

(2020) [Figure 5]. Spatial devices such as access gates, traffic closures, widened gaps, mini roundabouts, raised intersections, chicanes, lane restrictions, and raised crossings can transform a driveway into a shared open space accessible to all users. To ensure an inclusive approach to planning, it is necessary to introduce solutions like these that guarantee visibility, clarity of priority schemes, and installation of common road signs. Improving living conditions must go hand in hand with improving environmental conditions. This involves reducing congestion, improving air quality, reducing noise pollution, and enhancing accessibility to various urban functions. Additionally, it is crucial to prioritize people and their comfort in urban mobility, as roads belong to everyone (Dondè, 2021). By redefining driveways as shared spaces, the transformation goes beyond the utilitarian function, contributing to a more sustainable and harmonious urban fabric. This holistic approach underscores the architect's role in not only shaping physical environments but also in cultivating a sense of community and well-being within urban spaces.

### **Design space Affordances for Sharing the Road**

The contemporary landscape of urban mobility is marked by innovations aimed at fostering sustainable transportation (Zhou, 2023) and the concept of 'affordances', rooted in ecological psychology, emerges as a pivotal tool. Affordances, as conceptualized by Gibson (1979) and Heft (1982), signify the psychological relational properties perceived by individuals when interacting with their socio-physical environment. An affordance is what a user can do with an object based on the user's capabilities. As such, an affordance is not a 'property' of an object (like a physical object or a user interface). Instead, an affordance is defined in the relation between the user and the object (Norman, 2023). In the context of road sharing, affordances manifest as opportunities and constraints within the road environment, influencing the safety and experience of vulnerable road users such as pedestrians, cyclists, and motorcyclists (Hodson, 2017).

Addressing the unique safety challenges faced by vulnerable road users involves multifaceted design interventions. The design and layout of street furniture, encompassing benches, lighting, kiosks, and other urban elements, must prioritize ergonomic considerations to maximize comfort and ease of use. Accessibility is crucial, requiring thoughtful design of ramps, walkways, signs, and other elements to ensure easy access for all, including individuals with disabilities. Ade-

quate lighting, clear signage, and well-designed green spaces contribute to the safety and comfort of public spaces.

Urban strategies that eliminate the conventional division between pavement and carriageway result in a diminished dominance of automobiles, offering a promising avenue to enhance safety and the overall appeal of urban centres. Despite these benefits, experiences indicate that the most vulnerable users, such as the elderly and visually impaired, struggle to navigate these spaces, fostering a sense of insecurity. Consequently, there is a pressing need to devise strategies that prevent shared roads from becoming exclusionary spaces for the most vulnerable pedestrians. The foundational step in designing a shared street involves rendering its operation visible and eliminating any ambiguity regarding priority schemes. Spatial affordances encapsulate the possibilities for action offered by urban spaces influencing behaviour and well-being (Lops, 2018). The relationship between behaviour changes and design interventions involves nudging, prompting, and enabling, with the ideal approach combining strategies to exploit all strengths:

- Street furniture design and layout: seating could be designed to encourage socialising, with an arrangement that encourages conversation and lighting that naturally guides people along a safe route.
- Accessibility: in addition to ensuring physical accessibility, the design of public spaces should incorporate affordances to guide people along the accessible route in an intuitive way.
- Lighting: adequate lighting not only contributes to safety and comfort but can also be designed to highlight safe pedestrian routes in an intuitive way, encouraging movement and use of public spaces.
- Signage, wayfinding, and information: the clarity of signage can be improved by integrating intuitive colours and symbols to guide people through urban space without the need for complex instructions.
- Green spaces: the arrangement of benches, children's play equipment and other facilities could be designed to clearly indicate their function suggests relax or social interaction, in green zones with a high quality of microclimatic e natural elements attention.

Shared streets, designed initially for assumed "normal" human abilities, present challenges for diverse populations, particularly vulnerable groups like the visually impaired and seniors. The concept of a

'comfort zone' for pedestrians, aligned with building faces, requires careful planning to provide a safe and unobstructed walking route. The comfort zone should be sufficiently wide to enable two pedestrians to walk comfortably side by side. Detectable surfaces, including warning surfaces and directional indicators, are essential for the navigation of blind or visually impaired individuals within shared spaces.

In urban environments, place affordances are perceived by specific individuals and can be multidimensional, encompassing social, emotional, cognitive, and cultural properties that provide psychological meaning. Therefore, in public spaces they include a wide range of action possibilities and opportunities that influence people's experiences and behaviours. The relationship between behaviour changes and project intervention consists of three avenues for design interventions [Figure 6]:

- Nudging, which involves subtle changes in the environment to soft encourage behaviour. In the context of shared streets, nudging could include design elements such as textured paving, raised crossings, and strategically placed street furniture. These features subtly guide pedestrians and drivers, signalling pedestrian priority and encouraging slower vehicular speeds without relying on explicit signage.
- Prompting, which involves more direct and explicit cues to encourage behaviour. In the context of shared streets, prompting could include the installation of share road signs at entry/exit points and intersections, reminding drivers of pedestrian priority. Additionally, promptings could involve directional signage and tactile indicators specifically designed to assist visually impaired individuals in navigating shared spaces safely.
- Enabling, which involves providing resources and support to facilitate behaviour. In the context of shared streets, enabling behaviours could involve the provision of amenities such as seating arrangements, green spaces, and uniform lighting throughout the area, which enhance the overall comfort and appeal of the space for pedestrians. Furthermore, enabling could include the incorporation of detectable surfaces and warning indicators to assist visually impaired individuals in navigating shared streets independently. Design guidelines for shared streets, which seek to organically reduce vehicular speed through the removal of traditional signs and curbs, introduce an element of uncertainty for

drivers. However, the immediate effectiveness of these measures in altering behaviour is constrained and contingent upon cultural predispositions.

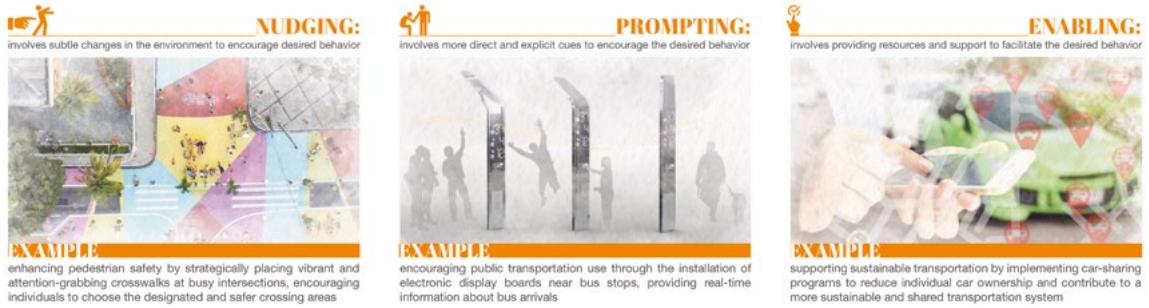


Figure 6. Behaviour changes and project intervention: nudging, prompting, enabling.

Furthermore, each type of intervention must be verified based on the dimensions of effectiveness and acceptance by users. Sustainable behaviour will result from a multidimensional and integrated intervention, and the ideal approach could therefore be a combination of strategies with multiple dimensions to exploit all strengths in one strategy (physical design intervention for behaviour change).

Users' diversities and limitations, that are crucial to discuss in relation to the different walkability performance of the streets, are to be strongly considered, and should be implemented, also in relation to shared streets concept.

## Conclusion

The imperative shift towards sustainable mobility planning in urban contexts requires a holistic approach that prioritises the well-being and safety of all road users, acting on travel times, which must be based on slow transport in cities. The traditional focus on accommodating cars over the last century is exacerbating climate change factors and causing congestion, safety risks and lack of accessibility for pedestrians and cyclists. To remedy this situation, a paradigm shift is needed that puts people at the centre of urban design and reimagines dynamic streets as public spaces (Gehl, 2013).

Spatial devices and affordances reshape the times of road sharing,

favouring an environment that encourages the use of sustainable modes of transport, promotes safety and improves the overall quality of urban life, but they need a strong policy. In Italy, slow legislative changes have embraced shared road concepts and need to be pursued and implemented to dismantle a car-centric highway code.

Urban affordances, rooted in ecological psychology, highlight the importance of designing urban spaces to meet the different needs and abilities of all people. Nudging, prompting, and enablement becomes crucial in influencing behaviour and promoting a culture of sustainable transport choices also for inclusive design strategies that prioritise accessibility and safety in shared spaces.

As we explore the complexities of sustainable mobility, the optimisation of equipment and spatial opportunities must be pursued. Understanding how these elements can be adapted to specific urban contexts, considering the multiple dimensions of effectiveness and user acceptance, will be crucial in shaping the future of urban mobility. The way forward is to co-create cities where streets are vibrant, shared spaces that improve the quality of life for all.

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#### *Attributions*

*Luciana Mastrolonardo is the author of "Introduction", "Design space affordances for Sharing the Road" and "Conclusion". Angelica Nanni authored the chapter "Spatial Devices for Sharing the Road".*

*All figures are original drawings by Angelica Nanni.*

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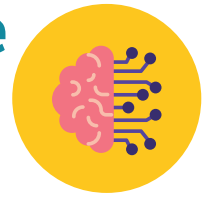


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# Health and safety executive indicator tool (hse-it) as a cognitive ergonomics management tool



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Keywords: ergonomic management; HSE-IT; sustainable development goals (SDGs); stress; mental health.

## Abstract

The use of tools that can quantify psychosocial risks and establish hierarchical levels of action is extremely important, as this is the start of the intervention process. Faced with this challenging scenario for companies, this study applied the Health and Safety Executive - Indicator Tool (HSE-IT) questionnaire as a cognitive management tool to cover the seven categories: demand, relationship, control, position, change, managerial support and colleagues. A random sample of two thousand one hundred and thirty-four workers from the administrative and operational areas of a meatpacking industry, with a total workforce of twelve thousand seven hundred and ninety-one workers, took part in this study. The results of the HSE showed that among the group of administrative and operational workers, the control and managerial support categories in-

**terfered with work-related stress, but in different percentages in terms of the degree of risk, being higher in the operational group. With regard to absenteeism, despite the absence of activities requiring musculoskeletal overload, the administrative sector had a higher average number of days off than the operational sector. With regard to the average number of days off work due to mental disorders, there was an equivalence between the sectors evaluated. The conclusion is that integrating HSE-IT into occupational health increases the capacity for early diagnosis of imminent problems, boosting the implementation of effective solutions by increasing the synergies between the environment and occupational health and safety and their relationship with ESG commitments (environmental, social and governance).**

## **Introduction**

The human factors related to the physical, technological and social aspects that make up the work environment have an impact on human behaviour and have been little observed by organizations. The stimuli of the work environment will have a positive or negative impact on worker satisfaction, influencing their performance, comfort and productivity. (GUIMARÃES, 2004).

According to DEJOURS, 2005, work cannot be considered neutral in relation to workers' health, as it can contribute to the development of musculoskeletal disorders, or have an impact on mental health, which is related to individual characteristics, the ability to manage thoughts, emotions, behaviours, social, cultural, economic and political factors (OSBORN, 2022). Personality and psychosocial characteristics are individualized, and contribute in isolation to an individual's mental health (COUTO, 2014).

AREOSA, 2021 describes that during the 1980s the fields of ergonomics, psychology, sociology, psychoanalysis, medicine and anthropology contributed to the discussion of this issue. In the following decade, the discipline of psychodynamics of work emerged to intensify the discussion on the effects of work on mental health, moving away from being just a negative factor and considering the positive aspects it can provide. According to the World Mental Health Report, the COVID-19 pandemic has created a global mental health crisis, where psychosocial risks contribute to short- and long-term stress. We can quickly define psychosocial risks as factors that can contribute to or even trigger stress and physical and mental illness in peo-

ple. Psychosocial risk factors are therefore linked to the way workers interact with their work, including professional performance, control, autonomy, the way tasks are carried out, work organization and the characteristics of the organization. (PEREIRA, 2020).

The statistics on mental health in the world are significant. Estimates point to an increase in the number of anxiety and depressive disorders of more than 25% during the first year of the pandemic. Around one in eight people in the world live with a mental disorder. In general, the economic consequences of mental illness include loss of productivity and other indirect costs for society (World Mental Health Report, s.d.).

In Great Britain, of the 1.8 million workers who have a work-related illness, 914,000 are related to stress, while 477,000 are related to musculoskeletal disorders. (HSE: Information about health and safety at work, s.d.).

Each case of stress-related illness generated an average of 29 days of lost work and cost approximately 18.8 billion pounds in injuries and health problems from current working conditions (HSE: Information about health and safety at work, s.d.).

According to the World Mental Health Report, s.d., almost one billion people were living with a mental disorder.

In Brazil, around 124,339 workers had a work-related illness, 23,202 were related to mental disorders, while 73,237 were related to musculoskeletal disorders (2021/2022).

For MIGUEZ, 2017, a more holistic and top - down view of this issue is needed, where physical, cognitive and organizational ergonomics are observed simultaneously, bringing contributions to Sustainable Development Goal (SDG) No. 8 of the United Nations 2030 Agenda. This approach can be found in macroergonomics, which emphasizes the interaction between a company's psychosocial and organizational contexts.

Faced with this challenging scenario, where a company's main resource is its people, we looked for a tool that could help manage possible psychosocial risks at work in order to implement control measures to protect workers from work-related stress. ISO 45003:2021 states that mental health management requires the use of specific tools to assess and quantify the risks related to stress levels. In Italy, Legislative Decree 81/08, also known as the Consolidated Law on Health and Safety at Work, makes it compulsory for all organizations, regardless of the sector of activity and degree of risk, to carry out a

work-related stress assessment. (Decreto Legislativo 81/08, s.d.-a). The Health and Safety Executive (HSE) questionnaire was selected as the cognitive management tool in this study. The HSE instrument defines stress as "the adverse reaction that people have to excessive pressures or other types of demand placed on them". Stress is perceived by the worker when they find it difficult to cope with the pressures or other issues present at work (HSE: Information about health and safety at work, s.d.). As such, this study provides results that can help companies consider ergonomics in the sustainability of their business, adding value for customers, workers and society.

## Method

The HSE-IT is an instrument with 7 categories and 35 items (table 2) developed by the HSE, the executive body responsible for the prevention of psychosocial risks in the UK, which makes it possible to identify the causes of stress related to the main categories reported by workers at the organizational level (LUCCA, 2023).

The HSE was chosen for the study because it presents a management model for stress management and because it covers seven categories: demands, relationships, control, job title, change, support from management and colleagues.

A random sample of two thousand one hundred and thirty-four workers from the administrative and operational areas of a meatpacking industry, with units in different regions of Brazil, with twelve thousand seven hundred and ninety-one workers on its staff, took part in this study. There were a total of fifty-four sectors, divided into eighteen administrative sectors and thirty-six operational sectors.

The participation of the workers was voluntary, and the objective of the study and the completion of the HSE questionnaire were explained beforehand by the ergonomist of each unit, who kept the identity of the participants confidential, based on the data protection law (LGPD).

A high response rate was taken into account in this study, which is important to ensure that the results correctly reflect the company's situation. As a rule of thumb for a survey of this type, a response rate of more than 50% can be considered adequate; more than 60% desirable, more than 70% good and more than 80% very good (table 1). With a response rate of less than 50%, the data should only be considered indicative and treated with extreme caution (REIS, 2019).

The HSE questionnaire (table 2) has thirty-five questions with five answer options, which are marked in a self-report questionnaire by the

workers on a Likert scale: (0) never; (1) rarely; (2) sometimes; (3) often and (4) always. (REIS,2019).

Table 1. Sample of the questionnaires.

Total numbers of workers	Minimum sample size recommended ( 5%)
500 or fewer	All the workers
501 - 1000	500
1001 - 2000	650
2001 - 3000	700
More than 300	800

Source: Reis, 2019

Table 2. HSE questionnaires.

	Items	(0)	(1)	(2)	(3)	(4)
1.	I know clearly what is expected of me at work					
2.	I can decide when to take a break					
3.	At work, different groups make demands on me that are difficult to reconcile					
4.	I know how to do my job					
5.	I am subject to personal harassment in the form of rude words or behavior					
6.	I have impossible deadlines to meet					
7.	If work gets difficult, my colleagues help me					
8.	I get feedback on the work I do					
9.	I have to work very hard					
10.	I can decide on my pace of work					
11.	I'm aware of my duties and responsibilities					
12.	I have to put some tasks aside because I have too much to do					
13.	I know my department's goals and objectives					
14.	There is friction or animosity between coworkers					
15.	I can choose how I do my job					
16.	I don't get enough breaks					
17.	I understand how my work integrates with the organization's objectives					
18.	I'm pressured to work for long hours					
19.	I can choose what to do at work					
20.	I have to work very quickly					

21.	I'm subject to embarrassment at work				
22.	I suffer absurd time pressures				
23.	I can count on my immediate boss to help me solve problems at work				
24.	I get the help and support I need from my colleagues				
25.	I have some say in how I work				
26.	I have enough opportunities to question my bosses about changes at work				
27.	I am respected as I deserve by my colleagues				
28.	The team is always consulted about changes at work				
29.	I can talk to my immediate boss about something that bothered me at work				
30.	My working hours can be flexible				
31.	My colleagues are willing to listen to my work-related problems				
32.	When changes occur at work, I am informed about how they will work in practice				
33.	I receive support when doing work that can be emotionally draining				
34.	Relationships at work are tense				
35.	My immediate boss motivates me at work				

Source: Reis, 2019

The questions are grouped by category for analysis and averaging of responses. The answers (table 3) were grouped by sector for analysis of the sector's organizational and psychosocial climate in an Excel spreadsheet.

For the dimensions of control, managerial support, colleague support, position and change, the answers marked "never" and "rarely" were considered and quantified as indicative of stress. The demands and relationships dimensions, on the other hand, have an inverted scale, so that the answers marked "always" and "often" were considered indicative of stress (De Lucca, 2017).

Next, the result (tables 4 and 5) showed scores, which are divided into risk bands for the level of action (REIS,2019).

For the demand and relationship categories, the interpretation is shown in table 4.

For the categories control, position, changes, support from the manager and support from colleagues, the interpretation is shown in chart 5. For the dimensions of control, managerial and colleague support, position and changes, the answers marked "never" and "rarely" were considered stressful. The demands and relationships dimensions, on the other hand, have an inverted scale, so that the answers marked "always" and "often" were considered indicative of stress (REIS, 2019).

Table 3. Categories x item evaluated.

Categories	Items	Response
Demands	03. At work, different groups make demands on me that are difficult to reconcile 06. I have impossible deadlines to meet 09. I have to work very hard 12. I have to put some tasks aside because I have too much to do 16. I don't get enough breaks 18. I'm pressured to work for long hours 20. I have to work too fast 22. I suffer absurd time pressures	(0) Never (1) Rarely (2) Sometimes (3) Frequently (4) Always
Control	02. I can decide when to take a break 10. I can decide on my pace of work 15. I can choose how to do my job 19. I can choose what to do at work 25. I have some say in how I work 30. My working hours can be flexible	(0) Never (1) Rarely (2) Sometimes (3) Frequently (4) Always
Relationships	05. I am subject to personal harassment in the form of rude words or behavior 14. There is friction or animosity between coworkers 21. I am subject to embarrassment at work 34. Relationships at work are tense	(0) Never (1) Rarely (2) Sometimes (3) Frequently (4) Always
Job position	01. I know clearly what is expected of me at work 04. I know how to do my job 11. I am aware of my duties and responsibilities 13. I know my department's goals and objectives 17. I understand how my work integrates with the organization's objectives	(0) Never (1) Rarely (2) Sometimes (3) Frequently (4) Always
Changes	26. I have enough opportunities to question my bosses about changes at work 28. The team is always consulted about changes at work 32. When changes occur at work, I am informed about how they will work in practice	(0) Never (1) Rarely (2) Sometimes (3) Frequently (4) Always
Managerial support	26. I have enough opportunities to question my bosses about changes at work 28. The team is always consulted about changes at work 32. When changes occur at work, I am informed about how they will work in practice	(0) Never (1) Rarely (2) Sometimes (3) Frequently (4) Always
Colleague support	07. If work gets difficult, my colleagues help me 24. I get the help and support I need from my colleagues 27. I am respected as I deserve by my colleagues 31. My colleagues are willing to listen to my work-related problems Source:	(0) Never (1) Rarely (2) Sometimes (3) Frequently (4) Always

Source: Reis, 2019

Table 4. HSE-IT Result/Interpretation.

Result	Interpretation
3.1-4	High risk of stress
2.1-3	Moderate risk of stress
1.1-2	Medium risk of stress
0 - 1	Low risk of stress

Source: Reis, 2019

Table 5. HSE-IT Result/Interpretation.

Result	Interpretation
0-1	High risk of stress
1.1-2	Moderate risk of stress
2.1-3	Medium risk of stress
3.1-4	Low risk of stress

Source: Reis, 2019

## Development

### Results

To analyze the results, the sample was divided into two working groups: administrative and operational (figure 6). The sample for this study included the following sociodemographic variables: gender, color, age group, schooling, length of time at home and marital status (figure 7). To analyse the results, the sectors were grouped into two groups: administrative and operational (Table 8). With regard to psychosocial factors and work organization, the main categories of work stress factors were identified, according to the workers' perception. According to HSE-IT, intervention in psychosocial risks is related to the degree of risk, where the yellow band requires action to be taken quickly and the red band requires improvement and immediate action. The categories that fall into this situation are highlighted below. The group of administrative and operational workers responded that the control and management support categories interfered with work-related stress, but in different percentages in terms of the degree of risk, being higher in the operational group.

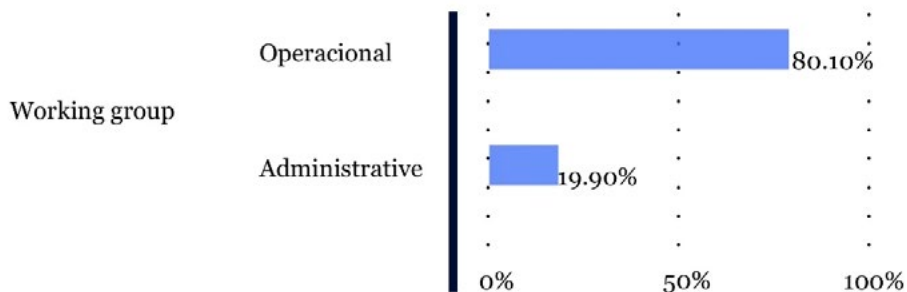


Fig. 6. Working group.

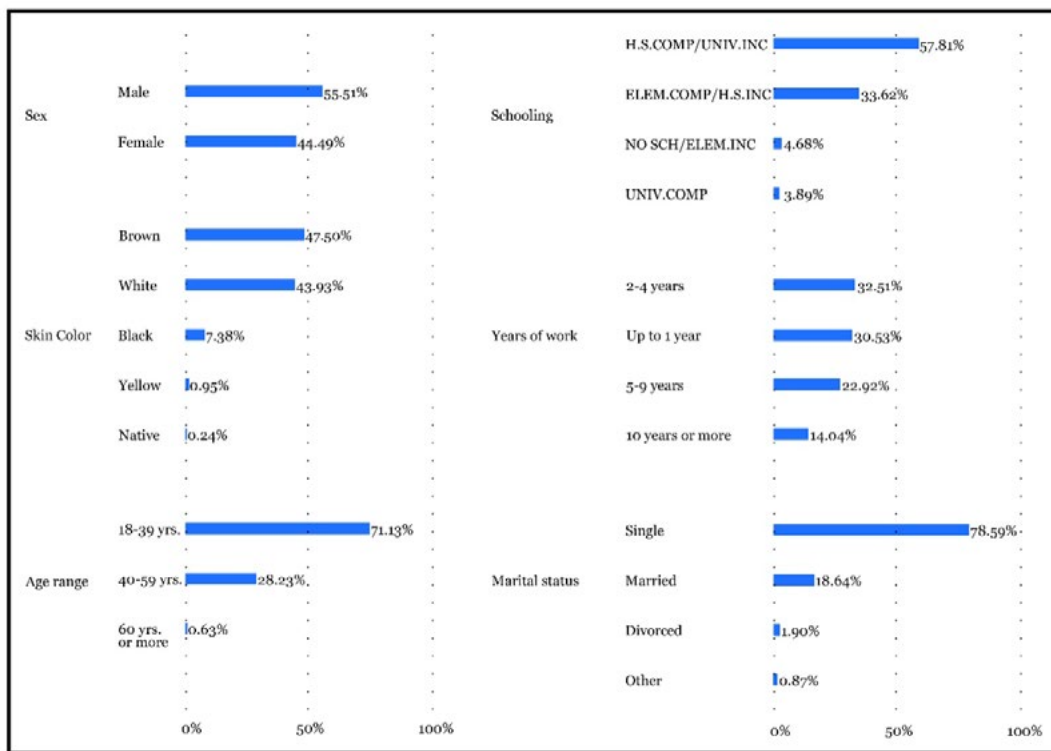


Fig. 7. Sample characterization.

Table 8. Results.

Working group	Category	Moderate degree HSE result	Number of moderate degree HSE sectors	High degree HSE result	Number of high degree HSE sectors
Administrative	Control	50%	9	33%	4
	Managerial support	22%	6	6%	1
Operational	Control	42%	15	47%	17
	Managerial support	33%	12	17%	6
	Relationship	19%	7	6%	2
	Change	33%	12	22%	8
	Colleague support	47%	17	6%	2

## Discussion

Macroergonomics allows us to broaden our view of the study of work activity, encompassing the fundamental concepts that all activity begins in the human mind, through perception, attention and memory, which are then transformed into mechanical actions to perform the task. (Iida, 2016). This approach with a global outlook intensifies the aspects related to human factors integrated into various concepts, which can contribute to compliance with Sustainable Development Goals (SDGs) 3 and 8 of the 2030 Agenda.

In addition to the well-being of workers, when ergonomic risks are reduced or eliminated, there is a reduction in fatigue and/or discomfort, thus contributing to improved performance, rework, consumption of natural resources and waste of materials, resulting in better strategic business planning.

The expected standards for the control category are that workers can have a say in the way and standards of their work; control the pace of work and develop their skills. In the managerial support category, the expected standards are related to the manager's support for their workers in relation to changes; feedback and access to the information needed to carry out the tasks. In the relationship category, it is hoped that workers will not suffer bullying at work and will be encouraged to report unacceptable behaviour, and that the organization will avoid conflicts by promoting positive behaviour. In the change

category, workers are expected to receive timely information about changes and impacts related to their work. For the peer support category, workers are expected to support each other through feedback and information needed to carry out tasks (REIS, 2019).

According to COUTO, 2014, control of the task is one of the main factors that keeps the individual in the zone of sustained adaptation. This is because it allows a sense of autonomy and authority, even in the face of other negative factors.

Situations of high effort and low reward at work can cause recurrent negative emotions and stress in the individual. Positive emotions stemming from social rewards, on the other hand, promote a sense of well-being. Thus, a marked imbalance between effort and reward can lead individuals with greater difficulty in adapting to various types of illness (SIEGRIST, 2012).

When we analysed the organization of work in both groups, it was observed that the operational work group has an organization focused on the pace of work in many sectors determined by machines or conveyors, prescribing the activity and operating mode in order to achieve product standardization and pre-established recovery breaks, factors which are present in the control category of the HSE-IT (table 3 category x items evaluated). In this respect, table 8 shows that the control category scored 47% higher in the operational group and 33% higher in the administrative group in relation to the high HSE-IT score, corroborating the characteristics of the work organization. In relation to the management support category, a higher percentage of 17% was also observed in the operational work group in relation to the high degree of risk in the HSE-IT results in table 8, compared to 6% in the administrative work group. The items evaluated in this category (chart 3) reflect possible inadequate communication between the manager and the worker, lack of support, direction and feedback on the work done.

When we analysed the absenteeism profile of the administrative and operational sectors, we saw a difference in the prevalence of absences due to musculoskeletal disorders. Despite the lack of activities requiring musculoskeletal overload, the administrative sector had a higher average number of days away from work than the operational sector. With regard to the average number of days away from work due to mental disorders, there was an equivalence between the sectors evaluated in this study.

Therefore, when the organization has a system aligned between ergo-

nomics and human factors, quality of life and well-being can be present in the workplace, contributing to integrative management.

Workload encompasses all the physical, cognitive and emotional efforts made to meet the demands of the tasks, which can cause physical and mental wear and tear, and is biopsychosocial and cumulative in nature (SELIGMANN,2011).

The effectiveness of the HSE-IT tool in the management of absences due to musculoskeletal pathologies presents significant advances in the field of occupational medicine and applied ergonomics. As demonstrated throughout this study, HSE-IT's ability to assess seven dimensions of work organization provides occupational health professionals with an evidence-based strategy for decision-making in order to make organizational environments safer and healthier to optimize human comfort and general well-being in line with Sustainable Development Goal No. 3 of the 2030 Agenda, thus minimizing cognitive overload.

It is particularly noteworthy that the tool has proved effective not only in operational environments, which are often associated with musculoskeletal risks, but also in administrative sectors. This suggests a universal applicability of HSE-IT, transcending the sectoral barriers common in occupational health intervention strategies for addressing human factors.

In short, HSE-IT is emerging as an indispensable tool for modernizing and making effective occupational health practices. Its adoption represents a significant step towards a safer and healthier working environment, corroborating the paradigm that prevention is ultimately more effective and economical than treatment.

## Conclusion

The study showed that the integration of the HSE-IT tool to assess and quantify risks related to stress levels, used by the ergonomics area and integrated with the company's occupational health area, facilitated the mapping of workers' mental health management in the organization, quantifying psychosocial risks and establishing hierarchical levels of action when necessary.

The results made it possible to draw up strategies for managing work-related stress, this being the initial intervention process (ISO 45001:2018 e ISO 45003:2021).

The ROI (Return on Investment) in health and safety programs makes the organization sustainable through measures such as improved

productivity, quality of life and greater efficiency in the consumption of resources. However, sustainable ergonomic management for the business is capable of observing labor rights, given the importance of labor in this line of business, as well as serving as a promising model for future research and practical implementation.

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# The energy cost of thermo-hygrometric comfort at the workplace



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Keywords: Comfort, energy saving, PMV, performance

## **Abstract**

**The Italian law (Legislative Decree 81/2008 and subsequent amendments and additions) mandates that the employer must always assess all existing risks at the workplace; this includes risks related to the exposure to inadequate thermal conditions, that may impact the workers' health or simply affect productivity levels. Following the risk assessment, the employer must implement preventative actions that often involve installing equipment for thermo-hygrometric control, and as such determine significant energy consumption with associated costs.**

**Adequate management of workplaces shows that efforts devoted to maintaining sensible levels of thermal comfort at the workplace are a good investment, because they protect the workers' health, increase their productivity and reduce the company's energy costs. Should these choices be made by many companies, they would benefit the environment by saving energy resources and reducing pollution due to the production of energy from non-renewable sources.**

## Introduction

The workers' well-being is an objective that employers should always pursue. Numerous studies have demonstrated that this condition determines an improvement in productivity and a reduction of the number and magnitude of accidents. Among the many aspects of comfort that should be taken into consideration, thermo-hygrometric conditions and indoor air quality both play a major role.

A first distinction must be made between workplaces that are considered thermally moderate and those that are considered constrained (del Gaudio et al. 2018).

In the first case, which can be associated with typical office conditions, there are no constraints on relevant environmental quantities, such as temperature or humidity, due to production needs. Therefore, thermo-hygrometric conditions can be regulated to values that make the work environment comfortable for workers.

In the second case, which can be associated with industrial or outdoor work, thermo-hygrometric environmental conditions cannot be adjusted by the employer. Prevention of risks for the worker's health can only be pursued by reducing exposure times, providing individual protection devices if possible, or create small air-conditioned areas where the continuous presence of the worker in the thermally demanding areas is not requested.

This paper shall focus on thermally moderate work environments, i.e. those in which comfort is a realistic objective, where the energy cost associated with maintaining adequate thermal conditions may not be negligible.

## Effects of ambient temperature on the worker

Numerous studies (Zhang et. al 2018; Bueno et al. 2021; Liu et al. 2021) have investigated the effects of ambient temperature on the level of mental concentration and have shown (Abbasi et al. 2019) that the executive functions of the brain are affected by very high and very low temperatures. Results are more controversial in thermally moderate environments. Temperatures that are too high or too low significantly increase the cardiac and respiratory activity of the subjects, with a long-term negative impact on their health.

With moderate air temperatures  $t_a \approx 22$  °C, a better balance of the sympathetic and parasympathetic vagal system is determined. Workers perceive improved thermal comfort, and perform better

(task accuracy). Figure 1 (Seppänen et al. 2019) shows that optimal performance is also achieved for  $t_a \approx 22^\circ\text{C}$ .

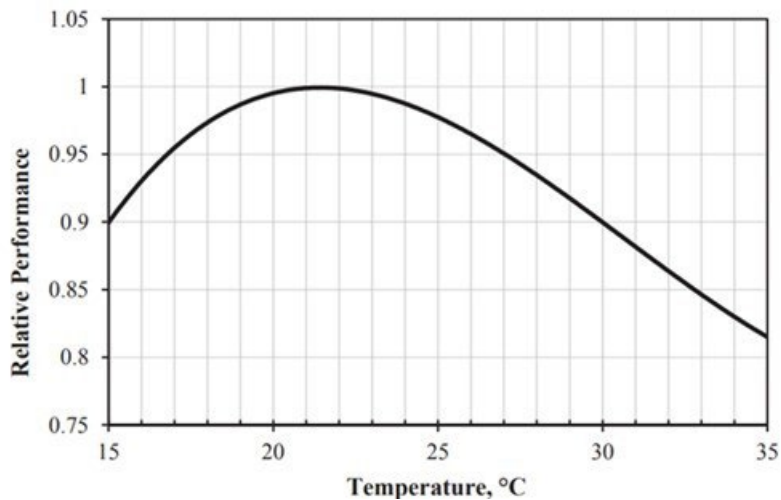


Fig. 1. Relative performance vs. temperature (adapted from Seppänen et al. 2019).

Thermal changes in the environment also activate the thermoregulation system of the human body. In the case of excessive heat (Utidjian 1973; Jacklitsch et al. 2016), in order to dissipate excess body heat, the human body activates vasodilation and sweating, which leads to a loss of fluids. In the case of excessive cold, it activates vasoconstriction and shivering, which produces heat by means of involuntary contractions of the muscles, resulting in energy consumption (Anttonen et al. 2009).

Under these conditions, physiological balances are altered, and for particularly sensitive subjects such as heart patients, even serious decompensations can occur.

### The hygrometric control of workplaces

Residential buildings and workplaces alike have traditionally been designed in Italy focusing on winter heating. This has typically implied using hot water heating systems providing convective heating. More recently, particularly in buildings where, for safety reasons, window opening was not allowed, systems were installed providing mechanical ventilation. Such ventilation systems were often combined with hot or cold fluid systems providing local air conditioning. Finally in the last decades there has been a huge deployment of

split air conditioning systems. These can provide adequate thermal conditioning in specific rooms/areas, but do not provide dilution of contaminants since there is no net inflow of outdoor air.

In this work we would like to emphasise that the main focus should be on the correct set-up of environmental parameters, regardless of the specific operating air-conditioning system.

## How thermal comfort is quantified

In order to assess the comfort level of people working in an indoor environment (either a residential building or a workplace), the Fanger method, known as the stationary or PMV method, has gradually become established over the last 50 years. In this method, once the type of activity that takes place in the environment has been identified, thermo-hygrometric parameters can be calculated in the design stage that shall guarantee comfortable conditions for the majority of subjects. The document that outlines how to choose thermo-hygrometric parameters for comfort optimization is the international standard EN ISO 7730:2005. Once appropriate equations have been established to calculate certain secondary variables (skin temperature and sweating rate), the energy balance of the human body can be written as a function of just six variables: air temperature, mean radiant temperature, air velocity, relative humidity, metabolic activity and thermal resistance of clothing. Experimental studies conducted by Prof. Fanger have established that the optimal comfort condition, where thermal acceptability is maximized, coincides with thermal neutrality, where the Predicted mean vote (PMV) is zero on ASHRAE 7-point scale.

As an alternative to Fanger's predictive approach, de Dear and Brager (1989) proposed an 'adaptive' approach by demonstrating that humans can adapt to the environment through their actions by, for example, modifying their clothing and physical activity. It has been shown that occupants of buildings without central air conditioning are more tolerant to temperature variations, and accept wider temperature ranges compared to occupants of buildings with central air conditioning, who do not have direct control over the parameters. The accepted temperature ranges are positively correlated with the outside temperature: as the outdoor temperature increases, the value of the preferred indoor temperature also increases, and viceversa. This approach is commonly adopted in residential buildings where subjects bear the full energy costs directly and have a strong mo-

tivation for making choices aimed at reducing such costs. This approach is not as easily applicable at the workplace, because the employer has to create conditions that are perceived as acceptable by as many subjects as possible. Only a predictive approach such as the PMV method is able to achieve a fair mediation between the needs of different subjects.

As in other areas of comfort (acoustic comfort or indoor air quality), the concept of acceptability is linked to maintaining the percentage of satisfied subjects above a minimum threshold. Two minimum thresholds that are often quoted are 80%, which represents the classic definition of a comfortable environment in the US standard on thermal comfort ASHRAE 55 (ASHRAE, 2017) since the 1980's, and 90%, which is implied by maximum acceptable fraction of dissatisfied of 10% set by Fanger around the same time, and included in the original 1984 version of the EN ISO 7730 standard.

*Table 1. Acceptability limits for the three categories A B C (EN ISO 7730:2005).*

Category	Thermal state of the body as a whole	
	PPD %	PMV
A	<6	-0,2<PMV<+0,2
B	<10	-0,5<PMV<+0,5
C	<15	-0,7<PMV<+0,7

A 90% threshold of satisfied subjects (i.e. a maximum percentage of dissatisfied subjects of 10%) is still often, albeit improperly, used as a reference for environments of any nature. However, the current 2005 version of EN ISO 7730 includes a modulation of the maximum allowed percentage of dissatisfied (PPD) into three categories, according to the scheme shown in Table 1.

The revision of the EN ISO 7730 standard initiated in recent months slightly modifies this scheme by adding a fourth category (Table 2), consistent with the European standard EN 16798-1: 2019.

Table 2. Acceptability limits for comfort categories (EN 16798-1:2019)

Category	Thermal state of the body as a whole	
	PPD (%)	PMV
I	<6	-0,2<PMV<+0,2
II	<10	-0,5<PMV<+0,5
III	<15	-0,7<PMV<+0,7
IV	<25	1,0<PMV<+1,0

As repeatedly emphasised in the literature (P. Lenzuni et al. 2009), EN ISO 7730 does not contain any criteria for assigning the environment under consideration to a specific category. CEN/TR 16798-2:2019 only includes qualitative definitions (Table 3) that are subjective and inconclusive in this context. A quantitative criterion has been developed (P. Lenzuni et al. 2009) but not yet included in international standards.

Table 3. Qualitative definitions of categories (CEN/TR 16798-2:2019).

Category	Expectation level	Definition
I	High	Level that should be adopted in the presence of individuals with special needs (children, elderly, handicapped)
II	Medium	Level normally used for design and use
III	Moderate	Level that maintains an acceptable environment. Introduces some risk of loss of performance.
IV	Low	Level that should only be adopted for a limited part of the year, in spaces with limited permanence

In many work environments, the presence of adults without specific pathologies engaged in the performance of activities that are not particularly 'critical' implies that such environments may be as-

signed to category III. Additionally, as explicitly stated in Table 3, environments with occasional occupation should be assigned to category IV. In these two latter cases, the appropriate upper limits of acceptability of PMV increase to 0.7 and 1 respectively (see Table 2).

## Comfort and direct savings

Tables 4 and 5 show the PMV and associated PPD values, calculated in typical office situations. Assumptions made include the mean radiant temperature set equal to the air temperature ( $t_r = t_a$ ), air velocity  $v_a = 0.1$  m/s, relative humidity  $RH = 30\%$ , metabolic activity  $M = 1.4$  met.

In table 4, a winter situation was analysed and therefore calculations were carried out considering a clothing thermal insulation  $I_{cl} = 1$  clo, whereas in table 5, a summer situation was analysed and calculations were carried out considering a clothing thermal insulation of 0.6 clo.

*Table 4. PVM and PPD as a function of the air temperature (winter situation).*

Situation	$t_a$	$t_r$	RH	$v_a$	$I_{cl}$	M	PMV	PPD
1	27,00	27,00	30	0,1	1	1,4	1,2	35,2
2	25,00	25,00	30	0,1	1	1,4	0,8	19,7
3	24,00	24,00	30	0,1	1	1,4	0,7	13,9
4	23,00	23,00	30	0,1	1	1,4	0,5	9,7
5	22,00	22,00	30	0,1	1	1,4	0,3	6,8
6	21,00	21,00	30	0,1	1	1,4	0,1	5,3

*Table 5. PVM and PPP as a function of the air temperature (summer situation).*

Situation	$t_a$	$t_r$	RH	$v_a$	$I_{cl}$	M	PMV	PPD
1	28,00	28,00	30	0,1	0,6	1,4	1,1	31,5
2	27,00	27,00	30	0,1	0,6	1,4	0,9	21,7
3	26,00	26,00	30	0,1	0,6	1,4	0,7	14,1
4	25,50	25,50	30	0,1	0,6	1,4	0,5	11,5
5	23,00	23,00	30	0,1	0,6	1,4	0,0	5,0
6	22,00	22,00	30	0,1	0,6	1,4	-0,3	6,3
7	21,00	21,00	30	0,1	0,6	1,4	-0,5	9,8
8	20,00	20,00	30	0,1	0,6	1,4	-0,7	15,8
9	19,00	19,00	30	0,1	0,6	1,4	-1,0	24,2

Had an erroneous set-up led to overheating as in line 1 (though it is not unlikely that under favourable weather conditions even higher values of temperature could be reached), the system would have wasted energy because comfort conditions would have been reached already in situation 3, corresponding to  $PMV = 0.7$ .

According to many bibliographical references (e.g. del Gaudio et al. 2018), in order to avoid excessive temperature jumps in the indoor-outdoor transitions, it would be advisable to cool indoor areas so that the temperature difference does not exceed  $7\text{ }^{\circ}\text{C}$ . Given that in recent years Italy has recorded summer outdoor air temperatures averaging  $35\text{ }^{\circ}\text{C}$  (with peaks of over  $40\text{ }^{\circ}\text{C}$ ), the indoor temperature should not be lower than  $28\text{ }^{\circ}\text{C}$ .

According to table 5, the maximum acceptable value  $PMV = 0.7$  is obtained for a temperature of  $26\text{ }^{\circ}\text{C}$ . However, in practice, lower temperatures are often preferred, by as much as  $3\text{ }^{\circ}\text{C}$ , leading to over-cooling and to improper energy waste.

Assuming that a large open space has an area of  $A \approx 1000\text{ m}^2$  and a ceiling height  $h = 3\text{ m}$ , the air volume will be  $3000\text{ m}^3$ . We can calculate how much this incorrect temperature regulation would cost the employer. The heat ( $Q$ ) needed to increase the air temperature, and similarly to decrease it, by a temperature differential  $\Delta T$  is:

$$Q = c_v \times V \times \Delta T$$

Given that the specific heat of air is  $c_v = 0.295\text{ Kcal/m}^3$ , the heat required to increase/decrease  $t_a$  by  $3\text{ }^{\circ}\text{C}$  is

$$Q = 0.295 \times 3000 \times 3 = 2655\text{ Kcal} \times h = 3.08\text{ KWh}$$

which is a more convenient expression since 'per KWh' is how energy is sold to the final user. For a full working day (7:30 a.m. to 7:30 p.m.), there will be an energy expenditure of  $3.08 \times 12 = 37\text{ KWh}$ . Since 1 KWh has currently an average cost of  $\text{€ } 0.113$ , we obtain a daily cost of  $\text{€ } 4.18$ , which for a typical average operating period for Italy of 180 days results in a total cost of  $\text{€ } 754$  for the winter season alone.

This calculation is obviously simplistic, since it does not take into account quantities such as the higher cost of starting up the systems after interruptions, the insulation characteristics of the building and, above all, behaviour such as opening the windows. The latter is unavoidable when there is no mechanical ventilation system, but it is also improperly used by workers as a temperature regulation system in the absence of other possible control actions.

## Conclusions

A very simplified simulation has been built to show how managing comfort correctly can also prevent energy waste. Excessive heating or cooling of workplaces can be avoided by using systems in which workers can directly act on settings. It is always desirable to make structural adjustments to improve the building's thermal insulation or the installation of blackout films or sunscreens. It is important to emphasize that in the absence of mechanical ventilation, it is important to ensure the proper renewal of air with intermittent window openings that have little effect on temperature if they are properly carried out.

As for the other risks, the employer must make use of new technologies whenever possible, by adopting structural solutions or upgrading systems, even if the cost effectiveness of such actions is not evident in the short term.

There is only an approximate match between the values considered optimal for thermo-hygrometric comfort and the performance level, so that a compromise solution must be found that also takes into account the associated energy cost.

It is always important to inform workers on the correct management of their working environment, avoiding energy-consuming behaviour such as incorrect temperature settings or prolonged opening of windows.

Recent regulatory changes stipulate that in the case of new constructions or major renovations, public buildings must make NZEB-type choices that do not use fossil fuels and tend towards energy autonomy through different sources. In this regard, solar systems (solar collectors) are being developed that can achieve high performance even in the presence of low levels of solar radiation with the production of high-temperature fluids that can be used for heating or to produce electricity (del Gaudio et al. 2023).

Finally, it is important to emphasise that workplaces have significant energy costs. All actions aimed at reducing energy consumption do not only increase companies' profits but can also contribute significantly to achieving the objectives set at global level by the most industrialised countries to reduce polluting emissions into the external environment and try to curb the effects on the climate.

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