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Edinburgh Napier University

Andrew Smith, Alasdair Reid, Mina Jowkar, Suha Jaradat (eds.)

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TWR NETWORK

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PREFACE

Welcome to the proceedings of the Fourth Transdisciplinary Research Network Conference (TWR 2024). This year's conference marks another milestone in our ongoing journey to foster collaboration and innovation to achieve our goal of contributing to the design and management of workplaces where people can work to their full potential and experience high levels of mental and physical wellbeing.

These proceedings present the latest findings of researchers, practitioners, and thought leaders from around the world who came together in Scotland's historic and vibrant capital city of Edinburgh to share their insights, discoveries, and visions for better workplaces from the 4th to the 7th of September 2024.

The Transdisciplinary Workplace Research (TWR) Network (www.twrnetwork.org) is a collaborative group of scholars and practitioners dedicated to enhancing workplace environments. Since its establishment in 2017, it has carried out its mission to disseminate groundbreaking workplace knowledge that enables organisations and individuals to reach their full potential, while maintaining high levels of mental and physical wellbeing. The network focuses on integrating various aspects of the workplace, including social, physical, technological, and managerial elements. This holistic approach ensures that workplaces support employee performance, satisfaction, health, and wellbeing. By bringing together experts from diverse fields, the TWR Network fosters interdisciplinary dialogue and collaboration. This approach helps translate academic research into practical solutions that can be implemented in real-world workplace settings.

The papers and presentations included in these proceedings represent the cutting edge of transdisciplinary workplace research. They span a rich range of topics including belonging, architecture and interior design, digitalisation and tools, wellbeing, educational and research workspaces, activity-based working, inclusion and diversity, engagement and culture, indoor environmental quality, workplace preferences, the evolving workplace, learning and education, corporate real estate, hybrid working, workplace experience and the human centred workplace. Each contribution underscores the importance of embracing a holistic perspective when it comes to workplace research and practice.

We would like to extend our thanks to all the authors and to the scientific committee, whose participation has made this publication possible. We must also thank the TWR Network and Board, in particular the Network Chair, Rianne Appel-Meulenbroek as well as the 2022 host, Chiara Tagliaro for the support that we have benefited from. We are also grateful to the School of Computing, Engineering and the Built Environment for making it possible to host the conference at Edinburgh Napier University. Thanks also to the university staff and volunteers who gave their energy to making the event a success, ultimately leading to these proceedings.

As you delve into these proceedings, we hope you find the research presented here as inspiring and enlightening as we do. Thank you for being a part of TWR 2024.

Andrew Smith, Alasdair Reid, Mina Jowkar, Suha Jaradat (eds.)
Edinburgh, September 2024

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Human occupation and behaviours VS environmental sustainability. An innovative calculation model to measure their effects in office buildings

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ABSTRACT

In the recent years, two major disruptions affected the construction sector. First, the climate change crisis addressed the need of reducing the environmental pressure of world economies. The rising importance of sustainability in both international policy debate and scientific field highlighted the importance for the sector to develop towards sustainability. Especially, the operation and maintenance has been identified as the most relevant phase on which the sector must focus in order to decrease its environmental impact. Second, the Covid-19 pandemic affected the global society by drastically changing human behaviours. More flexible ways of working have decreased the occupation level of office buildings. The increased level of uncertainty in offices' use showed the need to rethink the office space through the evaluation of users' occupation and behaviours.

Identified a gap in achieving an accurate impact assessment of in-use office buildings, this research implements a calculation model to measure the environmental impact while revealing the effects of human occupation and behaviours. The model, based on Ecological Footprint, identifies eight impact sources (built-up, energy consumption, water consumption, food & drink, material consumption, mobility, waste generation, and trade-off potential). The effectiveness of the model has been demonstrated by adopting the Participatory Action Research method, that allows to involve stakeholders (such as, facility managers and employees) since the beginning of the project. Calculations and results are reported by comparing nine case studies companies. This shows the potential of the model in addressing users and facility managers towards a more sustainable use of offices, which includes the comparison between office working and home working.

Going beyond energy efficiency, the research aims to answer the issue of office buildings use by adopting effective sustainability practices. Thus, the main advancement achieved is the development of a strategic framework that puts the roofs for steering a sustainable building management.

Keywords

Environmental sustainability, Workplace management, Facility management, Corporate real estate, User behaviour, Ecological Footprint.

INTRODUCTION

Office buildings are used differently after the Covid-19 pandemic has introduced more flexible ways of working (Hensher et al., 2022). Market trends and forecasts clearly highlight that, despite office market facing a downturn, environmental and sustainable features will be among the priority drivers of occupiers' workplace strategies over the next months and years (PWC and the Urban Land Institute, 2023). The pandemic represents an opportunity for offices to integrate more sustainable policies and practices by, on the one hand, reconsidering the amount of needed space and opportunity for downsizing and, on the other, during operation and maintenance (O&M). However, O&M is still an underestimated phase during which to foster energy reduction and sustainable practices. This study examines an innovative application of the Ecological Footprint (EF) as a sustainability indicator to be adopted in the workplace and facility management sector, exactly with the purpose to optimize office O&M. This can induce favourable changes in organizational policies and individual behaviour to support the UN's Sustainable Development Goals (SDGs). The role of the built environment in achieving SDGs is evident: 44% of the 169 SDG targets rely on construction and real estate activities (Goubran, 2019). In Europe, the sector accounts for about 50% of material consumption and a third of waste generated (ECORYS, 2014). Notably, 28% of GHG emissions result from the operational use of these existing buildings (WorldGBC, 2021).

Supporting the sustainable development and management of the built environment means to address cultural change both in building managers and in users. Even if the positive trends of sustainable transition are facilitated by certifications and ESG reporting encouraged by the EU, workplace and facility management still need an overarching scheme to integrate sustainable practices in office O&M. Understanding the use of Corporate Real Estate by observing user behaviour can offer new opportunities for integrating sustainable principles into office management (Hensher et al., 2022).

This study's objective is to propose an innovative calculation model for assessing offices environmental impact based on a relatively underexploited sustainability indicator, the Ecological Footprint (EF). We believe EF has the potential for measuring environmental sustainability in O&M and enhancing public engagement in managing building performance.

This paper unfolds as follows. First, it presents the current challenges in sustainability assessment, then introduces the EF methodology as a means to address current limitations. Later, it describes the experimental adaptation of the EF to nine case studies through a Participatory Action Research approach. Finally, it discusses the results and potential future developments of EF to improve office environmental sustainability in the O&M phase.

MATERIALS AND METHODs

Environmental impact assessment through international standards and indicators

Environmental impact refers to any alteration of the environment (physical, chemical or biological) caused by organizations' activities (ISO 14001:2015). ISO 14001:2015 highlights the need for organizations to identify, assess, and manage environmental impacts as part of their management to achieve environmental targets effectively. EN 15978:2011 provides a framework for measuring and reporting by considering the entire building life cycle. This framework sets indicators to be considered, such as global warming potential, resource depletion, and acidification potential. In addition, BS EN 15643:2021 provides guidelines to achieve the objective of empowering users, clients, and managers to make informed decisions that enhance sustainability performance and of communicating sustainability achievements to third parties, such as users or investors.

Besides, environmental certification protocols, such as LEED and BREEAM, have been implemented with the aim to define criteria and methodology for the evaluation of buildings' sustainability and overcome the information asymmetry between the construction sector and the building owners and users (Matisoff et al., 2014). Even if the environmental certification protocols have played a significant role in advancing sustainability in the sector by raising awareness and driving improvements in design processes (Mangialardo et al., 2019), they fail in offering a unified methodology applicable globally (Doan et al., 2017; Mangialardo et al., 2019). Moreover, most certifications focus on limited aspects of sustainability, such as energy efficiency or materials selection, focusing on the design and construction phases, and use weighted matrices to evaluate buildings. A complementary approach can be found in the EF methodology, which offers several benefits for implementing an environmental impact assessment to optimize offices O&M. First, the definition of impact provided by the EF expresses the environmental impact of activities as the combination of population (number of people), affluence (activities per person), and technology (intensity of resources use) (Wackernagel and Rees, 1996). Second, EF focuses on continuous measurement, instead of one-shot evaluation (Mancini et al., 2015). Third, the EF facilitates comparisons across regions (Wackernagel and Rees, 1996). Finally, the unit of measurement presents a clear and unambiguous message, that well addresses the call for engaging various stakeholders in sustainable behaviours (Mancini et al., 2015).

Ecological Footprint Methodology

The Ecological Footprint (EF) was proposed to quantitatively assess sustainable development and demonstrate that worldwide economies are living beyond the biophysical possibilities (Wackernagel and Rees, 1996; Lu et al., 2011). The EF of a population, whether it's an individual, an ecosystem, or an entire nation, represents the productive lands and water ecosystems needed to sustainably produce consumed resources, absorb emissions, and manage waste (Sala et al., 2013). The direct comparison of demand (represented by the population) and the supply (represented by the ecosystem's ability to regenerate consumption and absorb emissions) supports the understanding of the environmental impact of the system, expressed into global hectare [gha] (Wackernagel and Rees, 1996). The ability of the ecosystem is named "biocapacity", while the population's demand is referred to as "footprint" (Wackernagel and Rees, 1996). Biocapacity is expressed in "equivalent productive lands", encompassing built-up land, forest land, cropland, pastureland, fishing land, and CO_2 sinks (Borucke et al., 2013). The Global Footprint Network (GFN)[5], responsible for the EF index, defines factors like the World Yield Factor (WYF), converting impact sources into tons of CO_2, and the Equivalence Factor (EQF), converting tons of CO_2 into gha. These factors are established globally by comparing Earth's biocapacity with the human footprint.

Initially, EF evaluated the footprints of nations or regions, then extended to smaller environments like buildings (Pomè et al., 2021). Critiques of the original concept were necessary to improve the methodology and adapting it to the complexities of the built environment. Over the years, numerous contributions have been made to measure environmental impact of buildings, building systems, and building materials towards EF (e.g. Wood and Lenzen, 2003; Bastianoni et al., 2006;; Martínez-Rocamora et al., 2017; Husain and Prakash, 2018). The existing studies still miss the opportunity to consider all the impact sources and to measure the effects of users when assessing environmental

[5] *The Global Footprint Network is an international research organization that provides data and insights into humanity's ecological footprint.*

sustainability performance. Only one study (Pomè et al., 2021) proposed a draft EF model to measure the environmental impact of an office during O&M, but it failed in the collection of data and in proposing practical suggestions to facility managers.

Participatory Action Research method

Table 1. Participatory Action Research Methodology adopted for developing WIEFA model – elaboration of the authors.

Step		Name	Activities	Stakeholders involved	Year
1	P	Needs gathering	Collection of needs	Investors and property companies	2020
2	R	WIEFA framework 1	Calculation model	Investors and property companies	2020 – 2021
3	A	Experimental Application 1	Test on three case study buildings (Building A – B – C)	Facility managers	2021
4	P	WIEFA framework improved 1-A	Definition of data entry for the impact sources of the calculation model	Facility managers	2021
5	R	WIEFA framework improved 1-B	Definition of calculations to convert data into a common unit of measurement	Investors and property companies	2021 – 2022
6	R	WIEFA framework 2	Definition of the flowchart of the WIEFA model	Investors and property companies	2022
7	A	Experimental application 2	Test on five case study buildings (Building A – B – C – D – E)	Company managers	2022
8	A	Experimental application 3	Test on four case study buildings and comparison of the all nine case study companies (Building D2 –F – G – H)	Company managers	2022 – 2023
9	P R	WIEFA framework improved 2	Definition of the reporting data sheets	Company managers Investors and property companies	2023

To advance Pomè et al. (2021) model, the present study adopts a Participatory Action Research (PAR) methodology by involving different stakeholders in the process of model development and enabling cultural change (Wallerstain and Duran, 2001; Schneider, 2012). PAR emphasizes the collaboration between researchers and stakeholders to identify and solve problems during the research development (Reason et al., 2001). This study lasted 3 years including a Participatory (P) phase to engage stakeholders, an Action (A) phase to test the model with data collected through interviews, and a Research (R) phase to structure the calculation model. Four companies were involved throughout the whole model development process. The first scheme of Workplace Integrated Ecological Footprint Assessment (WIEFA) was structured by collecting needs from property managers and investors. Afterwards, an iterative research process took place in 9 steps between 2020 and 2023 with workplace and facility managers and office end-users (i.e. company managers) (Table 1).

The calculation model of WIEFA

WIEFA boundaries are defined as the difference between losses and gains stemming from three offices components: site, building, and users (Figure 1). For each of three categories, the WIEFA model identifies different losses and gains, that encompass Built-up, Energy Consumption, Water Consumption, Material Consumption, Mobility, Food & Drink, and Waste Generation. Meanwhile, gains include Trade-off Potential and Occupation (Pomè et al., 2021). Following on Brownell (2019), a holistic approach aggregating embodied footprint, operational footprint, occupant footprint, and influence footprint has been identified essential for a complete environmental impact assessment of offices, that considers user effects.

The model's boundaries of WIEFA define both the building and its site as physical limits. In detail, Built-up represents the area occupied by the building and paved; Energy Consumption considers consumption of electricity and fuels; Water Consumption measures the impact of consuming water; Material Consumption evaluates materials used for maintenance and cleaning activities; Waste Generation represents the impact of waste production. Users are a third order category that consume food and drinks (described by Food & Drink), access the building by different ways of transportation (represented by Mobility) and occupy the building. Advancing Pomè et al. (2021), occupation is not considered as input data but as a subsequent factor to interpret the results. To express the simultaneous occupation of users, WIEFA highlights simultaneous occupation as a variable to be factored into result reporting. Consequently, the impact of occupants on the overall footprint is not solely determined by their "consumption" of space but by their activities within the building (Figure 1). WIEFA results describe the potential benefit of "consuming" office space by more users via a new parameter expressed as gha/user. This parameter allows for a comparison between gha/employee year and gha/occupant year. The updated calculation model is presented in Table 2, along with the necessary data entry questions.

The calculations rely on factors that convert impact sources into global hectares (gha), allowing all addenda to be aggregated. Equivalent Factors (EQFs) serve as scaling factors that translate the actual usage areas of an activity into global hectares equivalence. The GFN offers the EQFs corresponding to the types of productive lands (Mancini et al., 2018; Pomè et al., 2021). In this research the EQF used are related to 2022:

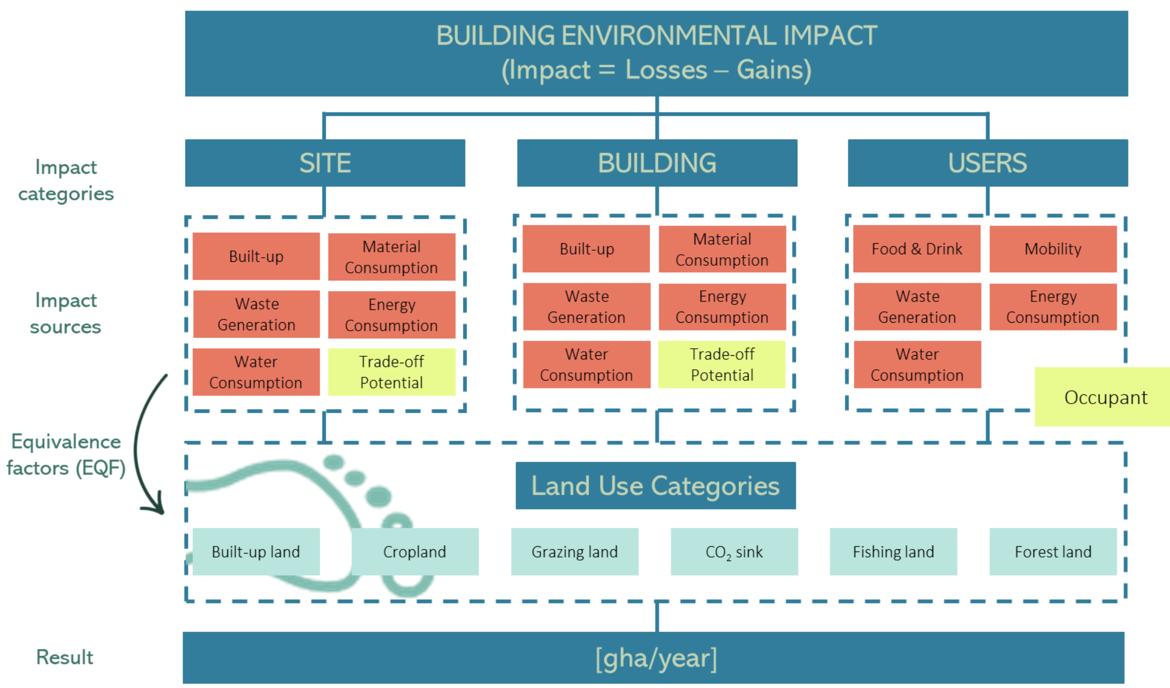

Figure 1. Workplace Integrated Ecological Footprint Assessment calculation model – elaboration of the authors

- Built-up land: 2,49
- Forest land: 1,28
- Fishing land: 0,74
- Pastureland: 0,46
- Cropland: 2,49
- CO_2 sink factor: 0,41

RESULTS

The case studies have been selected based on the following criteria:

1. The buildings must be a primary location of companies in Italy;
2. The organizations must belong to different industries and be all medium-large companies;
3. The buildings must vary in size and age;
4. A mix of workspace arrangements was sought: traditional workspace, activity-based workspace, coworking space.

The selected case studies (Table 2) represent a good mix of the factors described, which enabled an initial analysis of which factors most significantly influence the results, both in terms of building technological solutions and occupancy levels. The selected cases are located in Milano, Parma, and Brescia. The companies represent five different industries (pharmaceutical, facility management, technology, real estate, and multiservice companies) and count between 200 and 900 employees. The buildings vary in size and age from 6.000 to 44.000 square meters and from 1 year old to 73 years old, with various workspace arrangements.

Overall, the WIEFA application shows results in the same order of magnitude (from 237 gha/year to 1170 gha/year), which contributes to confirming the soundness of the methodology. In general, the age of the building results in a less efficient building system that causes a greater environmental impact. However, WIEFA is significantly affected by other aspects. For instance, by comparing Building D and Building H, it emerges that the environmental impact of Building D is greater due to the size of the building, entailing higher consumption not only of energy but also of water and materials, despite its more recent year of construction. Especially, its impact is remarkable when considering that the average occupancy does not exceed 50% which increases the account of WIEFA/occupant.

In sum, to understand the degree to which users' behaviours affect the environmental impact of offices, several factors emerge that highlight the potential of WIEFA in addressing sustainable principles to workplace and facility management, as follows.

Table 2.WIEFA results of the nine case study companies – elaboration of the authors.

YEAR	GENERAL DATA	CASE STUDY	BU	EC	WC	MC	F&D	M	WG	TOP
2022	Case study	**Building D-2**	6,43	566,85	6,78	27,12	168,11	135,10	140,24	-74,32
	Industry	Pharmaceutical								
	N employees	479								
	Average occupancy	230								
	Age	3								
	Location	Parma								
	Total SQM	30.503								
	Type of building	Office Building								
	Ownership / Tenant	1 Tenant								
	Workspace arrangements	Activity-based								
	Green Certifications	LEED Platinum								
Total WIEFA [gha/year]			**976,32**							
WIEFA/occupant [gha/occupant year]			**4,24**							
WIEFA/employee [gha/employee year]			**2,04**							
WIEFA/SQM [gha/m^2 year]			**0,03**							
Football fields			**1.367,39**							
2022	Case study	**Building H**	1,22	176,51	2,74	43,93	332,11	112,23	151,37	-0,4
	Industry	Multiservice								
	N employees	989								
	Average occupancy	363								
	Age	53								
	Location	Brescia								
	Total SQM	14.077								
	Type of building	Office Building								
	Ownership / Tenant	Owner								
	Workspace arrangements	Traditional								
	Green Certifications	/								
Total WIEFA [gha/year]			**819,70**							

YEAR	GENERAL DATA	CASE STUDY	BU	EC	WC	MC	F&D	M	WG	TOP
WIEFA/occupant [gha/occupant year]			***2,26***							
WIEFA/employee [gha/employee year]			***0,83***							
WIEFA/SQM [gha/m² year]			***0,06***							
Football fields			***1.148,04***							
2022	*Case study*	***Building G***	*1,15*	*282,47*	*3,42*	*40,61*	*57,70*	*68,64*	*120,20*	*-0,01*
	Industry	*Multiservice*								
	N employees	*937*								
	Average occupancy	*222*								
	Age	*73*								
	Location	*Milano*								
	Total SQM	*15.707*								
	Type of building	*Office Building*								
	Ownership / Tenant	*Owner*								
	Workspace arrangements	*Traditional*								
	Green Certifications	*/*								
Total WIEFA [gha/year]			***574,20***							
WIEFA/occupant [gha/occupant year]			***2,59***							
WIEFA/employee [gha/employee year]			***0,61***							
WIEFA/SQM [gha/m² year]			***0,04***							
Football fields			***804,20***							
2022	*Case study*	***Building F***	*1,04*	*83,06*	*1,81*	*9,82*	*126,40*	*50,08*	*24,88*	*-8,32*
	Industry	*Facility management*								
	N employees	*250*								
	Average occupancy	*162*								
	Age	*35*								
	Location	*Milano*								
	Total SQM	*6.161,7*								
	Type of building	*Office Building*								
	Ownership / Tenant	*1 Tenant*								
	Workspace arrangements	*Traditional*								
	Green Certifications	*/*								
Total WIEFA [gha/year]			***288,77***							
WIEFA/occupant [gha/occupant year]			***1,16***							
WIEFA/employee [gha/employee year]			***1,78***							
WIEFA/SQM [gha/m² year]			***0,05***							
Football fields			***404,44***							

YEAR	GENERAL DATA	CASE STUDY	BU	EC	WC	MC	F&D	M	WG	TOP
2021	Case study	**Building E**	2,22	34,46	0,48	10,96	248,03	116,15	24,88	-0,06
	Industry	Technology								
	N employees	338								
	Average occupancy	100								
	Age	3								
	Location	Milano								
	Total SQM	30.503								
	Type of building	Office Building								
	Ownership / Tenant	1 Tenant								
	Workspace arrangements	Activity-based								
	Green Certifications	LEED Platinum								
Total WIEFA [gha/year]			**437,12**							
WIEFA/occupant [gha/occupant year]			**4,37**							
WIEFA/employee [gha/employee year]			**1,29**							
WIEFA/SQM [gha/m² year]			**0,01**							
Football fields			**612,21**							
2021	Case study	**Building D**	6,43	672,21	6,78	41,39	200,67	146,67	167,91	-70,81
	Industry	Pharmaceutical								
	N employees	500								
	Average occupancy	250								
	Age	2								
	Location	Parma								
	Total SQM	44.000								
	Type of building	Office Building + R&D								
	Ownership / Tenant	Owner								
	Workspace arrangements	Activity-based								
	Green Certifications	LEED Platinum								
Total WIEFA [gha/year]			**1.171,25**							
WIEFA/occupant [gha/occupant year]			**4,69**							
WIEFA/employee [gha/employee year]			**2,34**							
WIEFA/SQM [gha/m² year]			**0,03**							
Football fields			**1.640,41**							
2020	Case study	**Building C**	1,17	27,33	0,37	15,74	51,80	116,16	23,95	0
	Industry	Owner (Real estate)								
	N employees	450								

YEAR	GENERAL DATA	CASE STUDY	BU	EC	WC	MC	F&D	M	WG	TOP
	Average occupancy	*450*								
	Age	*1*								
	Location	*Milano*								
	Total SQM	*34.000*								
	Type of building	*Coworking space*								
	Ownership / Tenant	*Owner*								
	Workspace arrangements	*Coworking space*								
	Green Certifications	*LEED Platinum*								
Total WIEFA [gha/year]			***236,52***							
WIEFA/occupant [gha/occupant year]			***0,53***							
WIEFA/employee [gha/employee year]			***0,53***							
WIEFA/SQM [gha/m² year]			***0,01***							
Football fields			***331,26***							
2020	*Case study*	***Building B***	*0,46*	*223,99*	*0,12*	*18,28*	*112,18*	*105,67*	*15,83*	*0*
	Industry	*Real Estate*								
	N employees	*850*								
	Average occupancy	*100*								
	Age	*16*								
	Location	*Milano*								
	Total SQM	*23920*								
	Type of building	*Office*								
	Ownership / Tenant	*1 Tenant*								
	Workspace arrangements	*Traditional*								
	Green Certifications	*/*								
Total WIEFA [gha/year]			***476,53***							
WIEFA/occupant [gha/occupant year]			***4,77***							
WIEFA/employee [gha/employee year]			***0,56***							
WIEFA/SQM [gha/m² year]			***0,02***							
Football fields			***667,41***							
2020	*Case study*	***Building A***	*1,17*	*644,02*	*2,46*	*13,63*	*194,79*	*115,15*	*14,93*	*0*
	Industry	*Technology*								
	N employees	*338*								
	Average occupancy	*100*								
	Age	*3*								
	Location	*Milano*								
	Total SQM	*30.503*								

YEAR	GENERAL DATA	CASE STUDY	BU	EC	WC	MC	F&D	M	WG	TOP
	Type of building	*Office Building*								
	Ownership / Tenant	*1 Tenant*								
	Workspace arrangements	*Traditional*								
	Green Certifications	*LEED Platinum*								
Total WIEFA [gha/year]			***986,15***							
WIEFA/occupant [gha/occupant year]			***4,40***							
WIEFA/employee [gha/employee year]			***1,42***							
WIEFA/SQM [gha/m² year]			***0,04***							
Football fields			***1.381,16***							

Impact sources

Looking at the impact sources, reported in Table 2, WIEFA is primarily influenced by energy and material consumption. Looking in detail at the WIEFA results of the nine case studies, some considerations can be highlighted.

First, the Built-Up (BU) area is determined by the ground covered by paved areas, parking lots, and the ground floors of buildings. Building D is the largest and occupies a larger area compared to the others. However, when comparing the percentage of the covered area (paved area over site area), Building D covers only 59% of the total site area. Situated outside the city center of Parma, Building D has the potential to include more green spaces. In contrast, Building C and G, located in the city centre of Milan, occupy 100% and 96% of their respective site areas.

Energy Consumption (EC) depends on the heating and cooling systems. Thus, buildings like Building A and F, which use fuel-based heating systems, have a higher EC per square meter. In contrast, district heating systems used by Building D, G, and H offer a good compromise for energy savings.

Water Consumption (WC) is greatly influenced by the presence of green areas. Thus, Building D consumes more water than the others.

Mobility (M) depends on the number of employees accessing the office daily and the location of the offices. A building in Milan, being more accessible via public transportation, impacts M less than a building in the countryside.

Fifth, Food and Drink Consumption (F&D) significantly depends on the presence or absence of a canteen.

Material Consumption (MC) depends on the renovations carried out during the analysed year. On average, cleaning activities do not significantly impact the results.

Waste Generation (WG) increases with the total square meters of the building and the occupation level. In large buildings (such as Building D) or in highly occupied buildings (such as Building H) the WG is higher than in buildings with green policies, such as Building E that promotes plastic-free office.

Finally, Trade-off Potential (TOP) depends on the renewable systems installed in the building. As it was expected that the older buildings would not have implemented renewable energies solutions, even in the most recent ones it was surprising to find few to no systems (for instance, Building C, renovated in 2020 and LEED certified, is only equipped with a set-up for photovoltaic panels, which are not in place yet).

Exogenous factors

The unpredictable use of office spaces following the Covid-19 pandemic affected the WIEFA results for both years of analysis. By 2022, organizations began to establish new policies for smart-working, providing clearer definitions for the occupancy levels of offices. This trend is also evident in the analysis of Building D that, in 2021, accounted for 1.171,25 gha/year, and decreased to 976,32 gha/year in 2022. Building D achieved savings of over 1.000 MWh in district heating and approximately 100.000 kWh in electricity. These savings were realized through the adoption of technological systems that control indoor and outdoor temperatures, monitor user occupancy and comfort, and manage entropy. However, this decrease can be attributed also to a reduction in the workplace population (from 500 to 479) and workplace occupancy (from 250 to 230).

Unit of measurement

WIEFA highlights the (in-)efficient use of office space by providing different units of measurement. For interpreting the environmental impact EF/m^2, EF/employee, and EF/occupant are compared. An older building's technological system (such as, Building A) negatively impacts WIEFA. Conversely, Building F, G, and H, which are older than Building A, appear to perform better. However, Building A performs slightly better than F on footprint per employee, showing that the environmental impact is shared by more people (i.e., the employees assigned to the building). This data contradicts the WIEFA/occupant ratio, as WIEFA for Building A was calculated in 2020, amid the Covid-19 pandemic. Building A also is evenly distributed over its square meter. On average, the total m^2 available for occupants is 2,4 times the m^2 allocated for employees, meaning that the space utilization could be spread across more people.

Other certifications

LEED certification doesn't necessarily mean a lower WIEFA compared to non-certified buildings. This is evident in Building D when compared to others. Despite using advanced technological systems for partitions and plants, Building D WIEFA per employee remains high (e.g., Building D-2 results 2,04 gha/employee for 2022 vs. 2,34 gha/employee for 2021), indicating ineffective use of office space.

Conclusion

This study contributes to enhancing attention to various aspects of sustainability while supporting the main objective of the European Union to harmonize environmental impact assessment for buildings. New smart-working policies being adopted by organizations may highlight the presence of extra office space that is not fully occupied. While to reduce operational and energy costs, offices might shrink in favour of flexible space utilization, optimizing energy and space efficiency also depends on the O&M phase. Therefore, a detailed analysis of individual office will be necessary to correlate employees' behaviours, working arrangements, and building occupancy.

This study adopted PAR to implement an innovative environmental impact assessment for workplace and facility management by exploring the EF methodology to address sustainability challenges in the O&M phase of offices. Specifically, incorporating user behaviour into environmental impact assessments and making impacts understandable to a wider audience, beyond just professionals and policymakers, were lacking in previous EF applications and became specific objectives of this research.

Noticeable is that, while implementing the PAR, the research team felt the need and the potential to progressively expand the panel of stakeholders. Participants covering the role of facility managers started being complemented with workplace managers, HR managers and energy managers. This may indicate that environmental issues are a transdisciplinary issue with cannot prescind from a human component and therefore should be managed both by professionals that usually have to do with the facilities' O&M and those who manage people (i.e. employees). WIEFA helps understand that people behaviour plays an important role in environmental sustainability, therefore sustainability strategy in offices is inherently linked with human resources and workplace management strategies.

Moreover, the results demonstrate the EF methodology's versatility in integrating user actions within buildings and confirm that the EF indicator is comprehensible to various stakeholders, including end-users (represented by company managers), workplace, facility, and HR managers of companies. This increased understanding marks a crucial step towards the progressive integration of EF into office environmental impact measurement and management. At the same time, it enables the evolution of cultural mindsets on sustainable behaviours and practices both on the side of those who manage buildings and on the side of those who utilize them. This supports workplace managers in developing strategies to optimize workspace utilization and reducing the building's environmental impact by influencing user behaviour.

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