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Indirect Economic Effects of Vertical Indoor Green in the Context of Reduced Sick Leave in Offices

Jutta Hollands * and Azra Korjenic

Research Unit of Ecological Building Technologies, Institute of Material Technology, Building Physics and Building Ecology, Faculty of Civil Engineering, Vienna University of Technology, A-1040 Vienna, Austria; azra.korjenic@tuwien.ac.at
* Correspondence: jutta.hollands@tuwien.ac.at

Abstract: Low indoor humidity has been shown to influence the transmission of respiratory diseases via air. A certain proportion of sick leave in offices is therefore attributable to dryness of air. An improvement in these conditions thus means a reduction in sick leave, which is accompanied by cost savings for companies. Vertical indoor greening has a verifiable positive effect on air humidity, especially in winter months. In this article, the correlation between improved air humidity in greened rooms and reduction of sick leave due to improved air humidity was described. The resulting indirect economic effect was determined by comparing the costs for construction, green care, and technical maintenance of indoor greenery with savings due to lower sick leave. Based on long-term measurement data on air humidity and temperature, and actual cost values for three buildings, located in Vienna, Austria, with 6 greened and 3 reference rooms without greenery, the correlation of the method was derived and finally formulated in a generalized way using dimensioning factors. Only considering the influence on air humidity, profitability of 6.6 m^2 vertical greening installed in an example office with six workplaces equipped with technical ventilation and saving of two sick days already results after about 4.5 years.

Keywords: hygrothermal comfort; indoor green; vertical greenery; indoor air quality; cost-benefit-ratio; sick leave; absenteeism; alternative quantification method

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Citation: Hollands, J.; Korjenic, A. Indirect Economic Effects of Vertical Indoor Green in the Context of Reduced Sick Leave in Offices. *Sustainability* **2021**, *13*, 2256. https://doi.org/10.3390/su13042256

Academic Editor: Roberto Alonso González Lezcano
Received: 2 February 2021
Accepted: 17 February 2021
Published: 19 February 2021

1. Introduction

People spend about 90% of their time indoors [1]. A large proportion of this time is spent in offices. In Vienna, the share of office workers in 2001 was 28.6% of all employees, and the trend is rising [2]. Moreover, in Germany, a rise in office working places can be observed, as a study shows: In 2020, 71% of all employees in Germany worked at least partly in an office, which means 32 million people, whereas in 2015, it was only about 52% (22.5 million) [3]. Austrian law assumes a normal working time of 8 h per day or 40 h per week [4]. For occupations that are mainly performed in offices, this thus accounts for a share of around 24% of the total weekly time. Due to this amount of time spent indoors, indoor air quality is also increasingly becoming the focus of numerous studies. In many cases, the quality of indoor air is rated as insufficient [5–8]. In addition to the detection of pollutants in indoor air, the temperature and climatic conditions are also the focus of investigations. Temperature and climatic conditions are perceived as the biggest disturbances in office work environment, directly followed by noise pollution [9,10]. Air humidity especially plays a very important role. The occurrence of the following health effects in working spaces is associated with too low humidity: Drying of mucous membranes, colds, eye complaints, skin complaints, and electrostatic charging and discharging [11]. Several studies have shown that the perceived indoor air quality is enhanced by indoor air pollutants, the protective mucous layer in the respiratory tract, and tear films. This results in complaints and diseases of the respiratory tract and eyes [5].

The question of the development of diseases, depending on the relative humidity, was already raised in the 1960s [12]. In this context, a connection between the survival of pathogens and relative humidity was established. Diseases or irritations of the skin, eyes, and upper respiratory tract are often associated with low relative humidity indoors during the cold season [5,13]. Dry, cold respiratory air favors infections of the upper respiratory tract such as colds and throat infections in particular [14,15]. This is probably due to a higher stability of virus particles at low humidity and low temperatures. This has already been shown for rhinoviruses [16], influenza A viruses [17], and numerous other viruses [16], which are typical pathogens of the common cold. Due to the increased stability, the transmission of these viruses is particularly favored. Studies have already been conducted to examine the effects of prolonged exposure to low humidity on perceived indoor air quality, sensory irritation symptoms in the eyes and respiratory tract, work performance, sleep quality, virus survival, and voice disorders. Results showed that an improvement in indoor humidity can have a positive effect on perceived indoor air quality, eye symptoms, and possibly work performance in the office environment [5,10,18,19]. However, effects on increased diseases are not only attributed to the higher stability of the viruses depending on the humidity, but are also caused by the influence on the host. Thus, due to low humidity, the host defense changes as well as tissue repair is reduced as Kudo et al. [20] showed in their study on mice. Lowen et al. [21] summarize as a result of their study with guinea pigs as model host the mechanisms of influenza virus transmission as a function of humidity at three levels: Level of host concerning the mucociliary clearance and the associated defense potential, level of particle concerning the stability of the influenza virions, and level of vehicle in the form of respiratory droplets. They state that there is a possibility of reducing influenza virus spread by "maintaining room air at warm temperature (>20 °C) and either intermediate (50%) or high (80%) RHs" [21]. These studies on animals will aid in understanding the ways and types of transmission between human populations [21].

However, it is important that the relative humidity does not reach too high values, as this allows selected viruses to survive, as well as the growth of mold spores and fungi. The relative humidity must therefore be within a certain defined range in order to achieve a positive health effect. This optimal range where overall health risks may be minimized regarding relevant biological and chemical interactions has already been defined in 1985 by Sterling et al. [22], with a relative humidity between 40–60%. This optimal comfortable range between 40–60% is also pointed out by Arundel et al. [23] as a result of their study. In this study, different studies from schools, offices, and barracks were summarized, which deal with the "indirect health effects of relative humidity in indoor environments" with the clear statement that absenteeism or respiratory infections were found to be lower among people working or living in environments with mid-range versus low or high relative humidity [23]. Other studies also came to the result of an optimal range of relative air humidity concerning the viability of bacteria and the viability of viruses [24], the virus stability and transmission rates [25], and the reduction of human stress levels in comparison to drier conditions [26].

Furthermore, temperature is also attributed an important role in the spread and the toll of influenza. Shaman et al. [27] therefore investigated the relationship between absolute humidity and influenza survival and transmission, with the result that this relationship has even stronger significance than when considering the dependence of relative humidity. The consideration of hygrothermal comfort as a function of not only humidity but also air temperature is therefore crucial. This connection has also been pointed out by Wolkoff [28] in his review article concerning indoor air humidity and air quality and their influence on health. He gives an overview of numerous studies conducted in schools, offices, hospitals, and factories investigating the influence of air humidity on ocular surface, sleep quality, and the airways, but also its influence on the survival of influenza virus with the conclusion that not only relative air humidity plays a decisive role, but everything that is connected to it such as air pollutants. Due to the complexity of this, more attention should be paid to the term of absolute humidity, as already done by [27].

These effects of low humidity in office rooms in the winter period inevitably manifest themselves in higher absences due to illness. Employees in Austria spent an average of 13.1 days on sick leave in 2018, compared to 12.5 days in 2017. Short absences due to illness (1–3 days) are very common and accounted for about 40% of all recorded sick leave cases in 2018. However, they are not recorded, which means that the actual sickness rate is higher. The most frequent causes of sickness are mainly diseases of the musculoskeletal and respiratory systems [29]. Together, these illnesses cause about 50% of all sick leave cases and 43% of all sick leave days. The overall economic costs of sick leave and accidents are made up of several components that can be measured with varying degrees of accuracy. While the direct payments made by companies and social insurance agencies in the form of continued pay and sick pay can be estimated relatively accurately. However, there is little evidence of the indirect economic costs or the medical treatment costs incurred in the health care system. In 2017, continued salary payments in Austria accounted for 2.9 billion euros, and a further 725 million euros were spent on sick pay. The directly attributable sick leave costs thus amount to 1% of Austria's GDP. Sickness-related absences from the workplace also lead to losses in added value and possibly to other operational costs (productivity losses, costs for replacement employees, follow-up costs of accidents at work, etc.) that exceed the direct costs of continued remuneration of the sick employee. These costs are difficult to quantify, as they vary greatly depending on the economic cycle, the industry, and the size of the company. Under highly simplified assumptions, it can be estimated that, in addition to the cost of salary replacement, sickness-related absenteeism generates indirect business and economic costs of 0.8% to 1.7% of GDP. In addition to these direct and indirect sick leave costs, there are also costs to the health care system in the form of medical care, hospitals, medication, etc. The above-mentioned cost factors are directly related to sickness absence; a decrease in sickness-related absenteeism has a correspondingly positive effect on these factors [30]. Not least because of the high costs involved, companies worldwide are striving to reduce absenteeism. Since the subject matter and the reasons for absences are very different and complex, different approaches to their reduction are also pursued. These include organizational measures related to the scope of duties, but also the upgrading of the workplace and the creation of a positive working environment in the offices with the aim of health promotion [31].

Milton et al. [32] investigated the connection between sick leave and indoor air quality among office workers in the USA. They established the link between the cost of sick leave and the currently recommended air exchanges, which, based on the length of sick leave attributable to air quality and the labor costs of an employee, can save about USD 400 per employee per year by improving indoor air quality through air exchange with the outside. In the mentioned article, ventilation is considered the main factor in improving indoor air quality. In any case, air exchange is the best way to prevent the spread of viruses and pathogens that are transmitted through the air. Moreover, the relative humidity influenced by humidifiers is included in this study with the knowledge that, in any case, too high humidity should be avoided, as this can not only lead to a higher survival rate of certain viruses, but also allows the development of mold spores and fungi. As also highlighted in Arundel et al. [23], maintaining a relative humidity between 40 and 60% should therefore be ensured. In their article, authors clearly state, supported by various epidemiological studies, that there is a significant correlation between absentee rates and relative humidity indoors. This correlation has also been investigated by Reiman et al. [33] in their study on humidity as a non-pharmaceutical intervention for influenza A in different classrooms. Comparing humified rooms to control rooms, they observed a significant reduction of the total number of influenza A virus positive samples. Taylor et al. [34] point out that there is a connection between low indoor relative humidity and reduced outdoor air ventilation and sick leave and productivity. Mendell et al. [35] suggest that health benefits for indoor workers by improving the building environments can lead to high economic benefits. One of the other measures they advise is the influence of temperature and humidity of air.

Indoor greening has many advantages. In addition to the aesthetic enhancement of the room, it can not only contribute to a reduction of the reverberation time and thus to better speech intelligibility, but also influences the air quality in a room. This has already been proven in numerous studies and investigations [36–38].

In particular, vertical indoor greening in the form of wall greenery has a great effect, since a large area of vegetation can be created on a small floor surface. Among other things, vertical indoor greening has a positive effect on hygrothermal comfort. Particularly in winter, this is a great advantage due to the health effects of too low humidity. This has already been shown by means of measurement data from [36] and international studies such as [39–41].

Further, Reimherr and Kötter [42] examined the effects of indoor greening in offices on health, well-being, and work performance in the context of a research project. Through their surveys, they found out that with about 55%, the psychological and psychosomatic effects have the greatest health-promoting effect, followed by the advantages of air humidification (30%). Furthermore, the reduction of dust and noise as well as the reduction of pollutants are also cited. Similar results were obtained by Fjeld et al. [43] through a survey addressing neuropsychological symptoms, mucous membrane symptoms, and skin symptoms through indoor air conditions among office workers. The situation with and without plants in the office was compared, and it was found that complaints regarding cough and fatigue were reduced by 37% and 30% through plants present. They though clearly suggest that foliage plants in offices can lead to an improvement in health and a reduction in symptoms of discomfort. Studies by Smith and Pitt [44] also show that plants can be a low maintenance tool to improve indoor air quality. Their in situ measurements show that plants can not only influence the humidity in offices, but can also influence other air pollutants such as VOCs.

Vertical indoor greening also has the advantage that very little to no floor space is lost in the room, and yet plants can be available in large numbers in the room. In comparison to individual plants in pots or troughs, however, wall plantings are associated with higher costs for installation as well as for the upkeep and maintenance of the technical system.

When making decisions about investments in buildings, costs and benefits are always weighed against each other. Cost–benefit analyses are therefore used to compare the monetary advantages and disadvantages. In a cost–benefit analysis, the value of a project is thus quantified in monetary terms with the aim of the support of social decision making on a rational basis. A plan is worthy of realization if, compared to doing nothing, the sum of its advantages is greater than the sum of its disadvantages [45], or as defined by Cambridge Dictionary, "the process of comparing the costs involved in doing something to the advantage or profit that it may bring" [46]. However, such cost–benefit evaluations are very complex for indoor and outdoor greening of buildings. This is not least due to the fact that the positive effects of the living, nevertheless technical, system of the vertical green are varied and not only the investor profits, e.g., in the form of energy saving, but also substantial positive effects on the health as well as also on the cityscape, which are so far difficult to quantify and/or in a further step to monetarize, as already explained in detail in [47]. A classical cost–benefit analysis is therefore not the correct instrument to illustrate the effects holistically for building greenery. Alternative assessment and evaluation concepts are therefore necessary.

In this article, the costs of an investment and operation of vertical indoor greening are to be examined and analyzed in relation to the benefits in the form of reduced sickness-related downtime in office buildings due to improved humidity thanks to the vertical indoor green. These comparisons and the conclusions drawn from them are based on the following context: Particularly in winter, interiors often have too low humidity. This has health effects for the people who stay in these rooms—this also applies to offices and the people who work in them and who are on sick leave because of these health consequences.

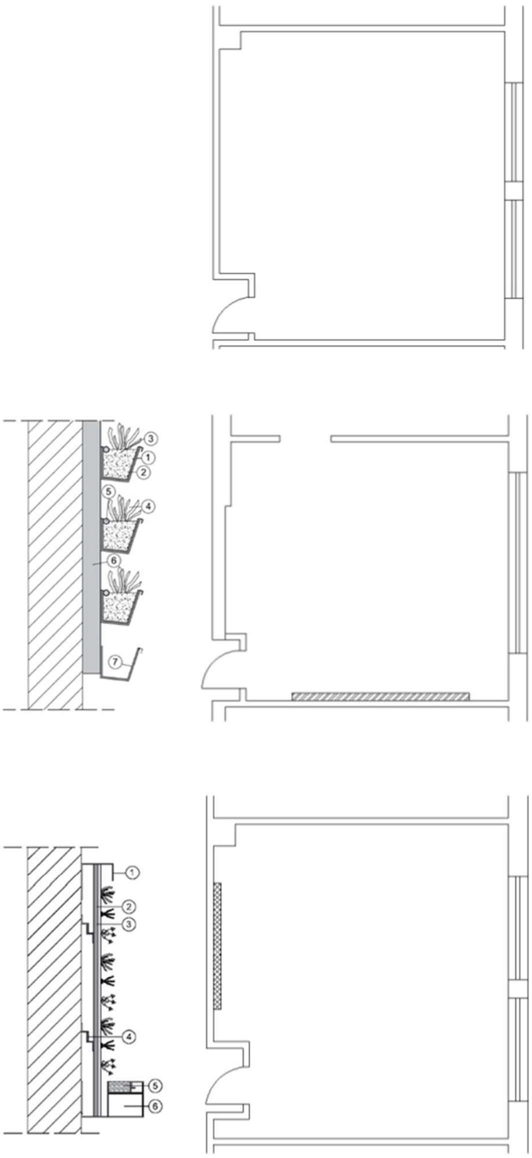
Vertical greenery improves the hygrothermal comfort in indoor spaces and, especially in winter, can contribute to an increase in air humidity to a comfortable level and thus also influence the associated health consequences. Sick leave due to health consequences and the associated absence cause costs for the company, which are reduced accordingly when sick days are reduced. Indoor greenery can contribute to this reduction, but it also causes costs for installation and maintenance. These costs for greenery and possible savings by reduced sick days are compared, and a method of quantifying and monetizing the effects of vertical greening is shown.

2. Methodology and Approach

In the context of the investigations for this article, a comparison was made between the cost savings due to less absence through illness and the costs for vertical greening in the interior of office spaces.

The investigations of this article are based, on the one hand, on the measurements of relative air humidity and air temperature in greened and non-greened interiors of three Viennese school buildings, which were equipped with different vertical greening systems within the scope of research projects. All project results can be found in [48,49]. These projects provided extensive long-term measurement data. The evaluations of the hygrothermal comfort for the classrooms in summer and winter have already been published [36]. In addition, recommendations for the dimensioning of vertical indoor greening in classrooms in relation to hygrothermal comfort were developed on the basis of formulas applied [49,50]. For the present study, the hygrothermal measurement data are filtered again and evaluated accordingly. This allows statements about the percentage of improvement of the hygrothermal comfort and thus the improvement of the indoor air quality based on this parameter. The three school buildings investigated differ in their construction method and in the way they are ventilated: A non-insulated old building in brick construction without technical ventilation system, a new building in reinforced concrete construction with a thermal insulation composite system and ventilation system, and one without a technical ventilation system. It is therefore possible to make statements for three different structural situations for these locations. They will be referred to as Building A, B, and C in the following. As an example for building C, Figure 1 shows the three different rooms as they exist in each of the three buildings: A reference room, a green room with the trough system, and a green room with the fleece system. This figure also contains the calculation results obtained. Figure 2 shows the greening with the fleece system as an example from building B.

The measured data of air humidity and air temperature were collected per building in two greened classrooms and one non-greened comparable classroom, which served as reference rooms, over several years in a measuring interval of 5 min. More details on used measurement instruments as well as measurement settings can be equivalently found in [36]. Two different vertical greening systems were used at each of the three locations: A fleece system and a trough system. These two systems were described in detail in [48,49] and shown in Figure 1 in a sketch. The plants used in the vertical greenings were selected within the framework of the research projects by the project partners with many years of expertise in vegetation technology as well as a landscape gardener involved in the project, so that the plant selection is optimally designed for use in vertical indoor greenings. The selection of the plants is attributed a high value, but this should not be the focus of the present investigations, but should always be accompanied by an expert. In order to be able to make statements about the effect of the greening also for office rooms, these measuring data from classrooms were filtered in such a way that only times in winter period when the rooms were not used for teaching were used for the present analysis, so that there is no influence of the presence of the students. In addition, all measured data were checked for plausibility, and data gaps and outliers were processed accordingly. In a further step, it was determined how many workplaces could be arranged in the respective classrooms in accordance with the Austrian workplace regulations. In this way, the vertical green area per workplace in the respective room under consideration was highlighted.



Reference Room – Not greened		
room size	64	m²
greenery size	-	m²
possible workstations	12	
m2-greenery per workstation	-	m²
installation costs for greenery	-	€/m²
costs for technical maintenance & green care	-	€/(m²·a)
improvement of hygrothermal comfort	-	%

Greened Room – Trough System		
room size	59	m²
greenery size	11.4	m²
possible workstations	11	
m2-greenery per workstation	1.0	m²
installation costs for greenery	1254	€/m²
costs for technical maintenance & green care	250	€/(m²·a)
improvement of hygrothermal comfort	408	%

Greened Room – Fleece System		
room size	63	m²
greenery size	5.6	m²
possible workstations	11	
m2-greenery per workstation	0.5	m²
installation costs for greenery	2375	€/m²
costs for technical maintenance & green care	400	€/(m²·a)
improvement of hygrothermal comfort	419	%

Figure 1. Overview of buildings and rooms with according calculation results.

Figure 2. Fleece system in Building B.

The hygrothermal comfort indoors and its criteria have already been examined in detail. In addition to relative humidity and air temperature, detailed analyses also take into account factors such as physical conditions, the activity of the persons, and their clothing. In order to enable statements as general as possible and in accordance with the available data, the definition of hygrothermal comfort according to Frank [51] is used in the present investigations and the measured values are analyzed according to these defined areas. This method is the same as that used in [36] for the analysis. Figure 3 shows these areas. Thus, measured values within the red framed area are in the comfortable range, which means that both the measured air temperature and the relative humidity are in a range that is comfortable for persons present. If a combination of relative humidity and air temperature is within the green framed area but outside of the red area, these measurements are called “still comfortable”. Outside of this green area, the existing conditions are considered “not comfortable”. This means that the temperature is either too cold or too warm, and the air is too dry or too humid.

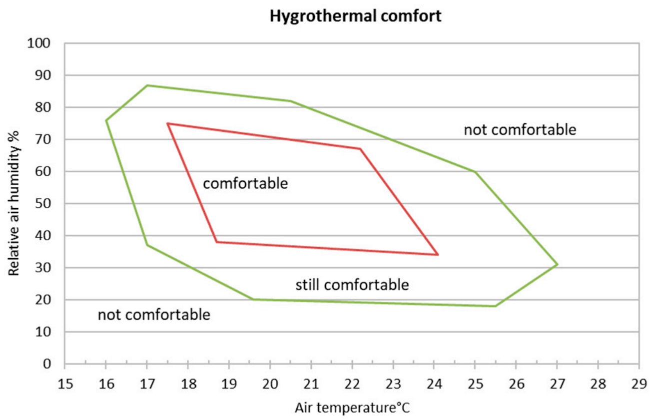


Figure 3. Hygrothermal comfort according to Frank [51].

The costs for the installation and construction of the greenery for the three locations were summarized and calculated on the basis of the actual costs incurred. Moreover, the costs for operation as well as green care and technical maintenance were collected and presented in values per year for the three locations and the two different greening systems used. Due to the locations as well as the different functioning of the greening systems, these vary. In summary, the costs of the greening systems could be calculated per workplace and year for each greening system used at the three locations.

In a further step, these costs are compared to the costs for the absence due to sickness of one person per day, which were determined based on the explanations in Section 1 and the average annual income of employed persons (including apprentices) and the working hours in hours per year according to Statistik Austria [52].

By improving the hygrothermal comfort in the greened rooms compared to the non-greened rooms, a reduction of the number of sick days is then possible on the basis of the correlations explained in Section 1, which allows a statement about the positive monetary effect of vertical greening in the office space on the saving of salary costs for employees due to fewer sick days.

In a final step, different initial situations addressing the connection between vertical indoor greening and reduced sick leave are considered. These should show in which way the method described in the article can be applied or which statements can be formulated based on the considerations. Situations such as the profitability of greening after a certain number of years or with a certain reduction of sick days per employee are considered before finally a generalization of assumptions based on dimensioning factors is carried out. Due to the compactness of the considerations, the approach is briefly described in the chapter of the actual calculation.

Cost-benefit analyses and also the method of evaluation presented in the context of this article have their limitations and only provide a decision support based on a comparison and do not represent an actual decision. They contain both value estimations as well as uncertainties and contain beyond that in principle no examination of legal defaults.

3. Results and Discussion

Following the procedure explained in Section 2, the next subchapters describe the considerations, calculations, and analyses performed and present the results of these.

3.1. Number of Workstations in Monitored Rooms

The monitored rooms are located in three different school buildings in Vienna, as already mentioned under 2. The nine rooms are six classrooms with greenery and three reference rooms without greenery. As can be seen in table in Section 3.5, all nine rooms have different room sizes and volumes—the room size varies between about 52 m^2 and 84 m^2; the room volume between 193 m^3 and 259 m^3.

According to the Workplace Ordinance applicable to Vienna, which among other things regulates the necessary size of a workplace in offices, "at least 8.0 m^2 for one employee must be provided plus at least 5.0 m^2 for each additional employee" per room in accordance with *§24 (1) AStV. §24 (3) AStV also stipulates that at least 12.0 m^3 of airspace per employee must be available "for work with low physical stress", which also includes normal office activities. [53]

In accordance with these legal requirements, the possible number of hypothetical workplaces in the nine monitored rooms was determined. The results are summarized in table in Section 3.5. The calculation was based on both the existing floor space and the air volume, and it turned out that for all nine rooms, the floor space was decisive. The number of workstations in the considered rooms ranges between 8 and 15.

3.2. Costs for Greening Systems

The construction as well as the green care and technical maintenance of vertical greening systems comes with costs. These are divided into investment costs, which are incurred once when the greening system is set up, and ongoing costs for plant care and technical maintenance of the system. The calculations also include costs for electricity and water consumption for lighting and irrigation of the green areas. They are divided into costs for green care and technical maintenance including fertilizer, plant material, as well as water and electricity consumption.

The costs considered in the research of this article are based on the real consumption of electricity and water measured in one of the schools and on the costs for green care and maintenance for the company that took over the maintenance after the end of the research project. The necessary lighting of the vertical indoor greenery is provided by LED strips or spotlights. The irrigation is done by a connection to the house water pipe and a micro-drip system according to the needs of each of the two different greening systems.

Due to the different functionalities of the two greening systems under consideration, the water consumption and the costs for green care and maintenance also differ. While in the trough system the plants are placed in technical substrate, comparable to a conventional flower pot, in the fleece system three different fleece layers are used for protection as well as for water distribution and storage. Since the plants are inserted bare-rooted into the fleece system and the fleece serves as a substrate substitute, the water consumption is significantly higher than with the trough system. Since this characteristic makes the system less resilient, the costs for care and maintenance are also higher than for the trough system. A more detailed analysis and explanation of the costs are included in [47].

Due to the comparability of the systems at the three locations, these real costs per m^2 known for one location are also used for the other two locations. Table in Section 3.5. contains the corresponding values for the six greened rooms.

The construction costs are incurred once only and are therefore allocated over the considered time period as shown in table in Section 3.5. This is done using a straight-line depreciation of the installation.

3.3. Costs for Sick Leave

The question to be answered in the following subchapter is: What does an hour and resulting from this a day of sick leave in an office cost? The winter period is considered in particular, since the frequency of sicknesses caused by low air humidity is highest during this period, and the effect on hygrothermal comfort due to indoor greenery is most significant.

Based on the conditions explained in Section 1 and on data from Statistik Austria from 2017, the average annual income of employed persons in Austria is 38,828 euros. If these costs are divided by the usual annual hourly rate of 1720 h per year, the average labor costs per hour per person are 22.57 euros. This annual hourly rate factor already includes the annual vacation days and public holidays. This results in labor costs of 180.60 euros for a regular 8-h workday. Table 1 contains the results of these calculations.

Table 1. Average labor costs of employed persons in Austria 2017 [54].

Average Annual Income of Employed Persons (Including Apprentices)	in EUR	38,828.00
Working hours per year	in h	1720
Working hours per day	in h	8
Average labor costs per day per person	in EUR	180.60
Average labor costs per hour per person	in EUR	22.57

The company incurs direct costs in the form of wage costs per person and working day of 180.60 euros. These costs represent only the direct costs as explained in Section 1. Not included are costs for, e.g., overtime of colleagues to compensate the workload or costs that arise from the delay of projects. Moreover, indirect costs for the health service as well as insurance are not considered. The actual costs for one sick day per employee are therefore significantly higher. Due to the existing data situation and the difficulties in the determination in particular of the indirect costs in the context of these present investigations, only the pure wage costs which must be further paid are taken into account.

Accordingly, the answer to the above question of the cost of one day of absence of an office employee can be answered: There are direct costs for continued payment of wages in the amount of 180.60 euros per day. Determining the indirect costs of absence is very complex and is therefore not quantified in this article.

3.4. Improvement of Hygrothermal Comfort

The measured data were evaluated according to the filter criteria and definition ranges for hygrothermal comfort (Figure 2) explained in Section 2. The results of these evaluations are shown in Table 2, and for one of the buildings as an example in Figure 4. It is clearly visible that the point cloud of the measurement data of the greened rooms (green measurement points) has clearly shifted into the comfortable area compared to the non-greened reference room (blue measurement points).

Based on the evaluations, it was calculated to what extent the greened rooms improve in comparison to the non-greened reference room. This percentage improvement is shown in Table 2. It can be clearly seen that all six greened rooms offer significantly higher hygrothermal comfort in comparison to the non-greened rooms and therefore have a healthier indoor climate. This also means that at no time was relative humidity too high, as is illustrated in Figure 4 for Building A as an example, so there is no risk of mold.

Due to the applied filter criteria explained in Section 2, these evaluations of the measured data obtained in school classes can also be applied to office rooms and, in particular, statements can be made about the winter period, which is important for sick leave due to respiratory diseases. The analysis of the monetary connection between the improved air quality and the days of sickness is presented in the next subchapter.

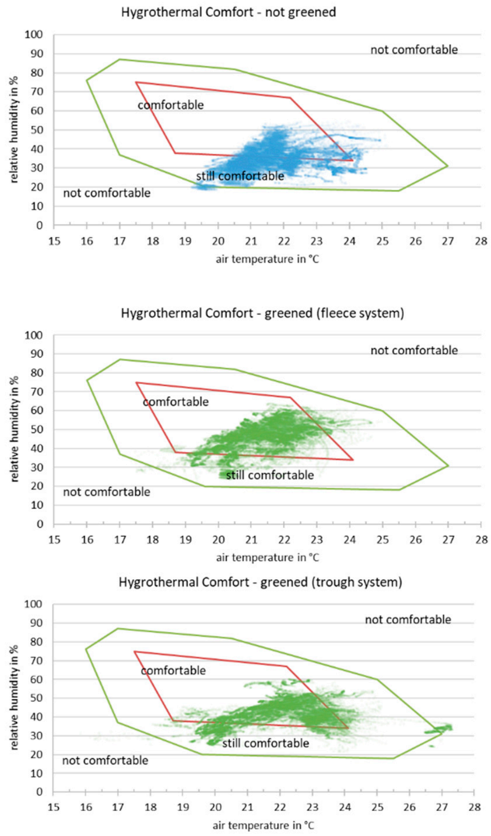


Figure 4. Hygrothermal comfort in not greened reference room and two greened rooms (fleece and trough system) for winter period represented by measured air temperature and relative air humidity with applied filter criteria (Building A).

Table 2. Evaluation of the measured data on hygrothermal comfort in the greened rooms compared to the reference rooms.

Building	Room	Comfortable		Still Comfortable		Not Comfortable		Total		Difference Greened to Not Greened (Comfortable)	Improvement Greened to Not Greened (Comfortable)
A	not greened	22,229	34%	42,916	65%	510	1%	65,655	100%	-	-
	greened (trough)	47,561	72%	17,039	26%	1055	2%	65,655	100%	39%	214%
	greened (fleece)	55,153	84%	10,445	16%	57	0%	65,655	100%	50%	248%
B	not greened	2659	19%	10,872	77%	659	5%	14,190	100%	-	-
	greened (trough)	10,499	74%	2370	17%	1321	9%	14,190	100%	55%	395%
	greened (fleece)	9466	67%	4678	33%	46	0%	14,190	100%	48%	356%
C	not greened	2566	17%	11,440	76%	963	6%	14,969	100%	-	-
	greened (trough)	10,476	70%	4486	30%	7	0%	14,969	100%	53%	408%
	greened (fleece)	10,752	72%	4127	28%	90	1%	14,969	100%	55%	419%

3.5. Connection between Vertical Indoor Greening and Reduced Sick Leave

The results explained so far and the calculation results described below are summarized in Table 3. This table also shows the procedure explained in Section 2. In the following subchapters, the connection between the improved indoor conditions thanks to greening and the associated costs for installation as well as green care and technical maintenance and the possible savings due to reduced sick days are studied by different approaches.

Table 3. Overview of the calculation results for all considered rooms and greenery systems.

Building	Room Size	Room Height	Room Volume	Greenery System	Greenery Size	Number of Possible Workstations According to AStV by m² [53] (3.1)	Number of Possible Workstations According to AStV** by m3 [53] (3.1)	m²-Greenery per Workstation	Installation Costs for Greenery Total [49] (3.2.)	Installation Costs for Greenery per m² (3.2.)	Costs for Technical Maintenance and Green Care per m² and Year [49] (3.2.)	Costs per Sick Day per Person [54] (3.3.)	Improvement of Hygrothermal Comfort (Comfortable) Greened to Not Greened (3.4.)	Installation Costs with Linear Depreciation on a Years per m² (3.5.1.)	Total Greenery Costs Yearly with Linear Depreciation on x Years per m² (3.5.1.)	Yearly Total Greenery Costs per Workstation	From … Days Less Sick Leave per Person It Will Pay Off to Have Greenery. (3.5.3.)	After … Years, Greening Pays Off with a Reduction in Sick Leave Per Person by d Day/Year (3.5.2)
	(m²)	(m)	(m³)		(m²)			(m²)	(EUR)	(EUR/m²)	(EUR/m²)	(EUR)	(%)	(EUR/m²)	(EUR/m²)	(EUR)	(d)	(a)
A	67	4	242	trough	17	12	20	1.4	21,500	1265	247	181	214	181	428	606	3.4	6.3
A	54	4	200	fleece	6.5	10	16	0.7	8200	1262	394	181	248	180	574	373	2.1	2.2
A	52	4	193	none	0	9	16	0.0	-	-	-	181	-	-	-	-	-	-
B	74	3	236	trough	9	14	19	0.6	9300	1033	250	181	395	148	398	256	1.4	1.4
B	82	3	259	fleece	5.6	15	21	0.4	14,500	2589	400	181	356	370	770	287	1.6	2.0
B	84	3	240	none	0	16	19	0.0	-	-	-	181	-	-	-	-	-	-
C	59	3	189	trough	11.4	11	15	1.0	14,300	1254	250	181	408	179	429	445	2.5	3.5
C	63	3	202	fleece	5.6	11	16	0.5	13,300	2375	400	181	419	339	739	376	2.1	2.8
C	64	3	206	none	0	12	17	0.0	-	-	-	181	-	-	-	-	-	-
						decisive								a = 7				d = 3.5

For each of the considerations and the initial situations described below, the green area per workplace in the different rooms was used. It is dependent on the size of the installed vegetation as well as the number of possible workstations in the room under consideration. This results in costs for the greening per workstation. The respective values are shown in the Table 3.

It is to be pointed out again expressly that in the following considerations, only the improvement of the air humidity is used as reason, however numerous further reasons speak for indoor greenery, which were not considered in the context of the present investigations due to so far lacking data. In Section 4, these connections are explained prospectively.

3.5.1. Initial Situation: Profitability after Seven Years Using Linear Depreciation

For this first consideration, it is assumed that the greening system as a technical system is depreciated on a linear basis over seven years—the installation costs are therefore spread over 7 years. The costs for green care and technical maintenance are considered as annual costs.

Assuming a usage period of 7 years, the following statement can be made depending on the green space considered: From d days less sick leave per person, it will pay off to have greenery. The number of d days varies between 1.4 and 3.4 (Table 3).

3.5.2. Initial Situation: Profitability after A Certain Number of Years

In a further step, the following statement shall be made: “With a reduction of d sick days, the construction of the greenery is already paid off after x years”.

To answer this, the annual costs for the greening per workstation are set in connection with the number of workstations in the room and the size of the greening and with the annual savings with reduced sick leave by a certain number of days at about 181 euros per day each. This can be calculated by the following Equation (1) and respectively Equation (2).

$$ws_{green} \cdot x \left(\frac{C_0}{x} + C_{care} \right) = C_{sick} \cdot d \cdot x \quad (1)$$

$$x = \frac{ws_{green} \cdot C_0}{C_{sick} \cdot d - ws_{green} \cdot C_{care}} \quad (2)$$

x—number of years; C_{sick}—costs per sick day per person; d—number of sick days; C_0—installation costs for greenery per m^2; C_{care}—costs for technical maintenance and green care per m^2 and year; ws_{green}—m^2-greenery per workstation.

3.5.3. Initial Situation: Reduction of Sick Days in Number of Days

Studies have shown that in greened offices with correspondingly improved humidity, sickness-related days of absence decreased by up to 3.5 days per employee [55]. The calculations based on the costs to be attributed to the greening and the saved wage costs calculated with Equation (2) show that the greening systems installed in the rooms are rewarded after only 1.4 to 6.3 years.

This large difference between the considered rooms or rather the exception with 6.3 years is especially due to the size of the greening with troughs in building A.

3.5.4. Initial Situation: Reduction of Sick Days in Percent

Another approach that has been followed is based on the correlation that statistically speaking, when humidity improves into a comfortable area, there is a certain percentage decrease in sickness absence due to respiratory diseases. As already explained in Section 1, this correlation has already been scientifically proven with regard to the transmission and survival of viruses at different levels of humidity. In addition, in an experiment described under [56], 30–40% fewer symptoms related to symptoms of the mucous membranes were detected. Based on their research, Fjeld et al. [43] found that plants reduce dry throat symptoms by 25% and coughing symptoms by as much as 37% due to the increased humidity in the room.

The reduction of these complaints results in reduced sick leave due to these symptoms. Here, an assumption of a reduction of 25% is made.

Based on the average number of sick days in Austria due to respiratory diseases, which were explained in Section 1, this results in a reduction of sick days by about 2 days.

This results in a profitability of the installed greening systems after between 3.3 and 12.7 years, depending on the greening system and area under consideration. Moreover, in this case, the large spread of values is due to the large differences in the size of the rooms and the installed greening systems.

3.5.5. Generalization of Assumptions Based on Dimensioning Factors

The calculations carried out so far are based on data obtained in the course of research projects in implemented projects. Within the framework of the research project, a formula for the dimensioning of vertical indoor greenery to achieve the optimum level of comfort in relation to humidity (relative humidity 45%) in the interior could also be developed. The dimensioning differentiates between technical and manual ventilation and between good and bad user behavior with regard to ventilation or the circulation of the ventilation system, i.e., the existing air exchange. Using these dimensioning factors, the necessary green area is calculated in m^2 depending on the floor area of the room (technical ventilation, circulation 1x per hour: 0.2; technical ventilation, circulation <1x per hour: 0.1; manual ventilation, good user behavior 0.08) [48,50]. Figure 5 shows the surface of an office depending on workplaces and the resulting surface of greenery for the different options of ventilation.

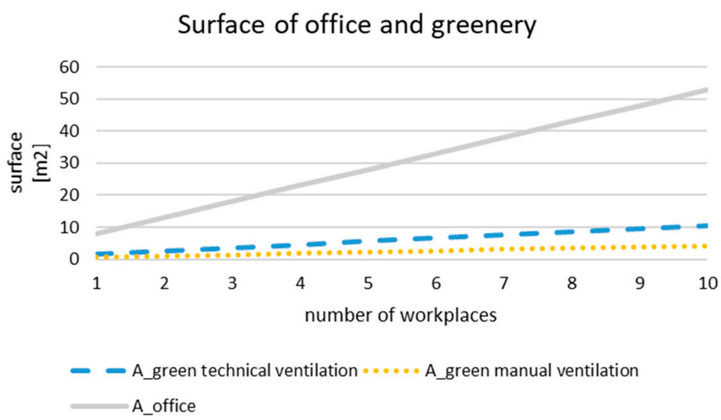


Figure 5. Surface of office (A_{office}) depending on workplaces (y) and resulting surface of greenery (A_{green}) with technical and manual ventilation according to dimensioning factor (g).

If the sizes of the greenery installed in the three buildings in Vienna are checked on the basis of these dimensioning factors, it is noticeable that they are significantly larger than those calculated after the dimensioning. However, this does not represent a contradiction, but the developed formula is in a way based on these research results. If the systems are too large in relation to the room size, there is a risk that the humidity in the room is too high due to the greenery. However, this fear could be excluded on the basis of the long-term measurement data. In other words: These effects can also be achieved with smaller surfaces only in relation to air humidity. However, if other effects are also considered, such as the influence on the room acoustics or aesthetic aspects, other greening areas may well prove to be useful. However, it is always necessary to pay attention to the increase in humidity and to select an optimum of effects. Last but not least, these effects also depend on the choice of plants.

Furthermore, this generalization now includes costs for installation as well as green care and technical maintenance based on current manufacturer information. These costs amount to 800 euros per m^2 for the installation and 150 euros per m^2 per year for the maintenance of the green care and technical maintenance.

Based on the calculations carried out for the model buildings, the following Equation (3) applies for a general dimensioning, whereby the following conditions apply ((4) to (7)). For an office space, the dimensioning factor thus results in a calculation according to Equation (8) for the number of years after which the installation of greenery based on reduced sick leave has paid off. Figure 6 visualizes these Equations for better understanding.

$$A_{green} \cdot C_{green,\ annual} = C_{sick,office,annual} \tag{3}$$

$$A_{green} = A_{office} \cdot g \tag{4}$$

$$A_{office,min} = 8 + 5\,(y - 1) \tag{5}$$

$$C_{green,\ annual} = \left(\frac{C_0}{x} + C_{care} \right) \tag{6}$$

$$C_{sick,office,annual} = C_{sick} \cdot y \cdot d \tag{7}$$

$$x = \frac{C_0}{\frac{C_{sick} \cdot y \cdot d}{A_{office} \cdot g} - C_{care}} \tag{8}$$

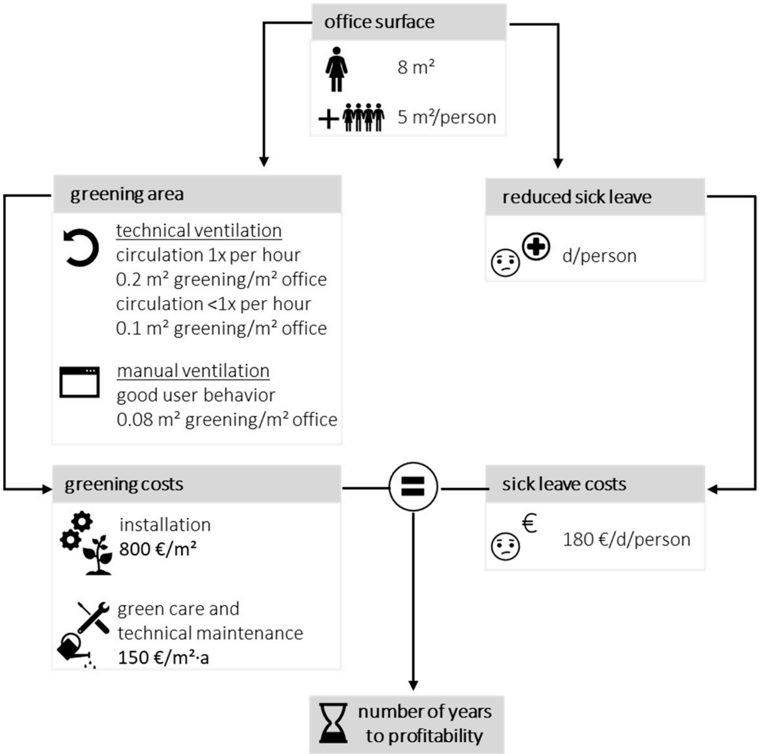


Figure 6. Overview of application of Equations (3)–(8) to calculate number of years to profitability of greenery through reduced sick leave.

A_{green}—surface greenery; $C_{green,annual}$—total annual costs for greening per m^2; $C_{sick,office,annual}$—annual costs for sick leave per office space; A_{office}—surface of office; y—number of work places; g—dimensioning factor for greenery; $A_{office,min}$—minimum size of an office for x employees; C_0—installation costs for greenery per m^2; x—number of years; C_{care}—costs for technical maintenance and green care per m^2 and year; C_{sick}—costs per sick day per person; d—number of reduced sick days.

For an office space with 6 workplaces and the minimum size of 33 m^2 specified by AStV and assuming technical ventilation and a circulation of 1x per hour (dimensioning factor 0.2) as well as the costs for the greenery according to the above-mentioned manufacturer's specifications, it follows that, assuming a reduction in sick leave by 2 days per person, the greenery will be profitable after about 4.5 years. For the same space with manual ventilation, the greening will be profitable already after about one year, since the size of the greened area of about 3 m^2 is significantly smaller than in the first example with 6.6 m^2. Figure 7 illustrates the number of years to profitability comparing the costs for greenery and the according benefits for reduced sick leave for different cases such as different sizes of offices (3 or 6 persons) and different reduction of sick leave (2 or 3 days) as well as different types of ventilation (manual and technical). Profitability is given as soon as the line of costs intersects with the line of benefits.

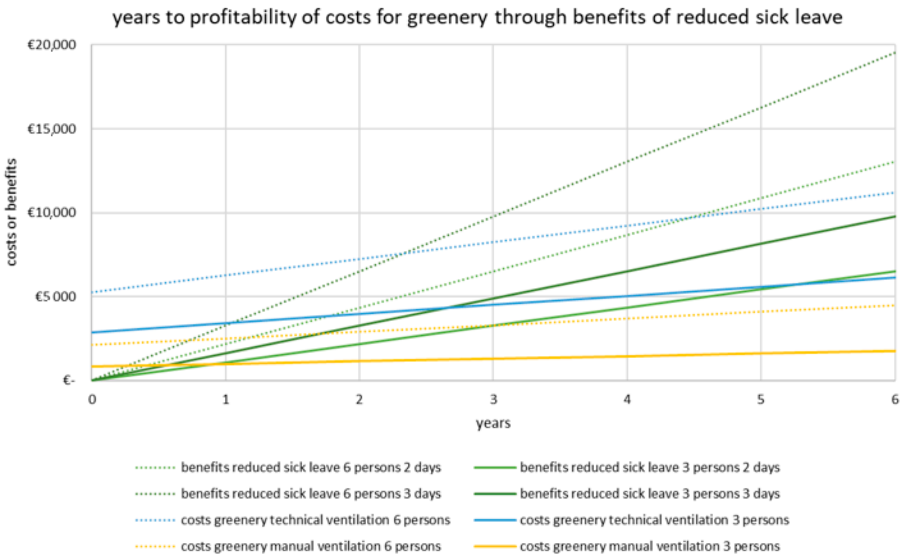


Figure 7. Years to profitability of costs for greenery through benefits of reduced sick leave for different cases.

4. Conclusions and Outlook

The calculations and analyses carried out have shown that an economic consideration of indoor greening in relation to its effects on sick leave in offices is definitely worthwhile due to the improvement of humidity in the room and its impact on human health.

The positive effects of vertical indoor greening on the relative humidity of the indoor air have already been proven worldwide and can also be confirmed for the six greened sample rooms under consideration on the basis of the analyzed measurement data. On this basis, the effects on an office space and the workplaces and employees located in it were derived.

The effects on sick leave were assumed in these studies based on expert literature and only the effect of improved humidity in the form of hygrothermal comfort was considered. Other known positive effects of greening have not been considered so far. In the office environment, these include in particular the improvement of the reverberation time and thus the influence on the room acoustics as well as the possible enhancement of the working environment through greening. It can therefore be assumed that there may be further positive effects on working life and employee satisfaction. In particular, unspecific clinical patterns related to sick building syndrome should be further considered in this context.

A comparison of these effects on the humidity of greenery with conventional air humidification systems or extended possibilities of building technology systems could also be made. However, such systems also cause costs for technical maintenance and, in addition, they only pursue the one benefit of the change in air humidity and, as technical systems, do not achieve any further advantages as is the case with greening.

It should be pointed out that this article is not a financial report, but presents a method to demonstrate and quantify the effects that have not been considered in investment decisions about vertical greening up to now.

Furthermore, it is to be differentiated in connection with the presented method between the macro economical costs of sick leave and the costs for one company, as was already explained in the introductory chapters. So far, only wage costs were considered, and no macroeconomic total calculation were aimed at, which would include also costs of insurance, hospitals, etc. The calculated profitability is therefore a conservative consideration.

Additionally, it must be taken into account that the calculations are subject to uncertainties and, especially when using living, technical systems and when considering the effects on humans, a generalization is not always exactly possible. Uncertainties exist, for example, with regard to personnel costs, prices of greenery, actual reduction of sick leave, as well as in the generalization of sick days and the assumption that the air quality in the office space considered was not optimal before. With regard to a practical application of this method by a specific company, however, it should be pointed out that the formulas presented, with their in-house data for personnel costs and sick leave, provide direct results that are subject to greater certainty.

In a further step, the extension of this presented method to other areas such as outdoor greening is possible. However, this expansion is more complex due to the fact that the effects and responsibilities cannot be clearly assigned. In the presented example of office space and the saving of wage costs, it can be assumed that the person who invests in the greening is also the one who benefits from the savings. Due to the different levels on which vertical greenery is effective in outdoor areas, as shown in [47], the analysis is therefore also much more complex. One instrument that should also be considered in this context is the Cost-Efficiency-Analysis, because it allows the intersection between buildings and urban planning to be made visible, which is also the focus of the greening of buildings.

Author Contributions: Conceptualization, J.H. and A.K.; methodology, J.H. and A.K.; validation, J.H. and A.K.; formal analysis, J.H.; investigation, J.H. and A.K.; writing—original draft preparation, J.H.; writing—review and editing, J.H. and A.K.; visualization, J.H.; supervision, A.K. Both authors have read and agreed to the published version of the manuscript.

Funding: Open Access Funding by TU Wien.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors acknowledge the TU Wien Bibliothek for financial support humans through its Open Access Funding Program.

Conflicts of Interest: The authors declare no conflict of interest.

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