

Design of Intelligent Construction and Environmental Governance Equipment Under the Dual Carbon Background—Taking a Wearable Secondhand Smoke Absorption and Purification Device as An Example

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Abstract: Based on the dual-carbon background and the requirements for smart construction and green practice, taking wearable used tobacco smoke absorber and purifier as research object, from the aspect of combining equipment functional design with low carbon development strategy, summarizes the main needs to be met by the second-hand smoke control at smart building site, and improves the function configuration and technical route of the purifier according to the low carbon design principle; the paper also discusses how to apply low carbon materials and energy saving technologies in the equipment design. providing a reference direction for improving intelligent construction environment management system towards low-carbon emission and high-intelligence level, whose results aim at promoting the synchronized development between on-site environment management and the industry's green, low-carbon revolution.

Keywords: Dual carbon context; Intelligent construction; Environmental governance equipment design; Wearable secondhand smoke absorption and purification device

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1. Introduction

Dual carbon objectives drive smart construction to go further into greener, lower-carbon directions. Environmental management on construction sites is the main part of green smart construction, and the development of environment management facilities should be based on intelligent management and low carbon needs. The wearable second hand smoke absorbing purifying machine is an environmental management facility that can be carried out in small-scale scattered places such as building sites. However, existing systems are problematic in terms of high energy consumption, higher embodied carbon for the material itself, and misalignment between functionality and specific construction tasks. In this paper we take this machine as an example of our investigation into ways that such function may be aligned with low carbon approaches, thus promoting green smart development direction of intelligent construction environment monitoring devices.

2. Design requirements for intelligent construction environmental governance equipment under the dual carbon initiative

2.1. Functional compatibility requirements for environmental governance equipment in intelligent construction scenarios

Smart construction site is featured with distributed workspaces, complicated working scenes, and high mobility of workers, requiring the environmental treatment equipment to be mobile, smart, and situational, able to adjust for different types of construction settings (e.g., elevated work, open areas, and closed workbenches, where pollutants can be identified quickly and treated promptly, for on-site real-time removal of contaminants (e.g., environmental tobacco smoke), and be user friendly: synchronizing with worker work-rhythms by means of a single click on/off button, as well as smart controls which avoid unnecessary interruptions in the building process, while maintaining stable performance under harsh conditions such as vibration, dust. Digital characteristics of smart building require the environment processing device has data collection and combination functions, which can realize the timely acquisition of field air quality information and device working condition information, and upload them to the smart management system for accurate control of construction site environmental conditions.

The functionality of this device should also be able to satisfy various needs, so that it can flexibly adjust its cleaning capacity according to pollution levels in each trade and workplace. Besides, it has good adaptability which can be combined with other smart devices in the site to form a comprehensive construction scene management system and improve the overall working efficiency.

2.2. Core requirements for low-carbon design of environmental governance equipment under the dual carbon framework

In the context of the dual-carbon plan, the green and low-carbon planning of ecological management facilities focuses on applying a series of green and low-carbon concepts from the selection of raw materials for ecological management facilities and facility production to use process. maintenance and recycling, to cut down on carbon emissions and energy use. At a materials level, preference would go to low-carbon, environmentally friendly, recyclable, low-carbon materials to substitute for conventional high carbon non-recyclable ones; thus, reducing the carbon footprint of its manufacture, where the fabrication is done by optimized methods using low energy, low-emission technologies for reducing energy use and emission of pollutants that control carbon footprint at the point of origin. The low-carbon strategy also includes energy-efficiency performance, lightweighting, product design for reduction of material usage while maintaining performance, reducing total equipment weight, and reducing energy consumption for both transportation and operation ^[1]. Energy efficient design concentrates on the power system and smart components, using low-power energy-efficient elements and power supplies with a reduced number of modes of operation for reducing the consumed energy. The recyclability is based on using modularity in design allowing replacing modules, maintenance, recycling, improving resource efficiency, decreasing waste production, and realizing a low carbon cycle throughout the life cycle.

2.3. Principles for coordinated design of functional intelligence and low-carbonization

Firstly, in the joint design of functional intelligence and low-carbon, it is necessary to follow the idea of “functionality first, low-carbon adaptation”, so that the low-carbon design will not affect the core function of environmental treatment equipment governance or its own intelligent level; with meeting on-site environmental governance requirement as the first priority, low-carbon ideas are involved in all aspects of the functional design, and when designing functions like intelligent identification, purification, and data collection, the low carbon character of innovation decision and part matching should be viewed together, not using high-energy-consuming or high-carbon-emitting technologies or materials just to be smart, thus achieving the balance between function and sustainable development, and the joint design should be based on “full process integration and systematization optimization”, low-carbon design: Low-carbon design is a systematic process

that integrates low carbon strategies into all stages of design for an environmental treatment facility, including conceptual design of its functions and technologies, layout design of components, and design of structure.

3. Core requirements and low-carbon correlation points of wearable secondhand smoke absorption and purification devices

3.1. Core functional requirements for secondhand smoke control in smart construction sites

The main function system of the wearable second-hand smoke adsorbing and purifying device for smart building site is to focus on effective adsorption and purification, while also integrating smart sensing capability, portability, and power efficiency into a “sensing purification–adaptation–monitoring” system in one piece. The efficient adsorption/purification core is with the hierarchical filter architecture that can efficiently adsorb and degrade toxic materials, including nicotine or tar in secondhand smoke; enabling localized air purifying. The smart sensing unit uses accurate smoke sensors for monitoring the current smoke concentration, enabling automatic activation/deactivation and power adjustment of purification functions, the design of the device is meeting requirements regarding portability, lightweight, and easy-to-operate features as well as wearability and usability for the working environment of construction workers, it has a long-life cycle. compact size to reduce disturbance in the workers’ movement and good waterproof/drop-proof/dustproof performances, making it applicable to the complex construction sites condition.

At the same time, the system should have basic features like electric power consumption monitoring and operation state indication so that the construction staffs could monitor the equipment condition at any time; it can be combined with simple air quality display function , can provide instantaneous information of how clean the ambient air is, thus achieving a balance between performance and practicability in terms of decentralized and mobile demands for SHS prevention around construction sites.

3.2. The intrinsic connection between the purifier function module and low-carbon design

Wearable secondhand smoke absorption purifier’s functional module is closely related to low carbon design, and the material choice function module is the core part of low carbon design. as the materials chosen to be used in the casing of the purifier itself, its filter parts and even the casings of the smart components directly affect the amount of carbon that is emitted when manufacturing and recycling them. Classic plastics and metals have a higher emission level, whereas the use of low-carbon eco-friendly materials can effectively reduce the total life cycle emissions. Low carbon goals are also related to the technical selection of adsorption purification modules: High power consumption fans, filters and filter elements will increase the amount of energy consumed, while low-power fans and recyclable filtering material achieve energy saving and emission reduction. Similarly, smart sensing unit and power supply unit also have significant impacts on low-carbon design, sensor choice in sensing unit will affect standby power and operating power, with low-power sensors to minimize wasted energy when they are inactive; and the power supply unit dictates how efficiently a sensor uses energy, as compared with conventional disposable batteries which not only consume too much energy, but also cause pollution to the environment, while rechargeable lithium batteries and solar powered energy can enable carbon-free operation ^[2].

3.3. Optimal approach to optimizing purifier function design under the low-carbon concept

Based on low-carbon thinking mode, the priority of optimization design for wearable secondhand smoke absorbing and purifying device is to upgrade the materials system towards low-carbon materials, which means replacing original high-carbon, difficult-to-recycle materials by eco-friendly alternatives like bio-based plastics, recycled carbon fiber and/or biodegradable filter material used in the casing of the device, wearable parts and filter devices. In terms of material strength and filtering effects, it can reduce the emission of carbon elements in production process and improve the recyclability and biodegradability of materials to reduce waste pollution. Low-carbon optimization technology selection and function structure is an important entry point for device design. favoring low-power, energy efficient smart devices and

components, low-power smoke detectors, energy efficient quiet fans, and low-power control chips. Purification system's design enables "on-demand operation" in order to reduce the excess energy usage.

Meanwhile, through unifying functional architecture, different intelligent functions integrate in one device to reduce the number of components and decrease materials cost as well as energy consumption. Additionally, decarbonizing the grid itself (e.g., developing more efficient energy sources such as solar-assisted electricity generation and fast charging, low-energy-use batteries for increasing energy efficiency, reducing reliance on fossil fuels and nuclear power;

4. Functional design of wearable secondhand smoke absorption and purification device under the dual carbon initiative

4.1. Architectural design of low-carbon intelligent adsorption purification function

The low-carbon intelligent adsorption purification system adopts a "micro-power sensing layer–low-power consumption purification layer–light weight filtration layer" three-layer structure, and the sensing layer uses micro-power smoke sensor scattered around the air inlet of the purifier, precisely sensing the change of ambient second-hand smoke density. Such sensor works on sleep mode that it enters low-power standby when there's no smoke around and wakes up quickly once the smoke is sensed so as to save the standby power consumption for sensor nodes. The purifying layer has an energy efficient, silent DC-motor fan with variable speed control, which adapts the air flow rate to the smoke density in order to clean only as much as necessary and minimize energy consumption. A thin filter consists of an environmentally friendly filter fabric, an activated carbon absorption layer, and a photo-catalytic decomposition layer. And the filter mesh is composed of biodegradable bio-based materials, the activated carbon layer uses recycled activated carbon and the photocatalytic part adopts low-energy photocatalyst which can degrade harmful substances in nature illumination instead of using a high-power UV lamp, thus increasing the filter's effectiveness and lowering its power requirements.

Our network is designed to be modular such that the different units within each layer can be used separately and also together. Our filters are plug and play, reusable, and recyclable, enabling future maintenance, improving the use of resources, and being low carbon, green buildings.

4.2. Module design for energy-efficient intelligent sensing and regulation function

The smart low-power consumption perception-control consists of three main functional blocks including the smoke detecting block, the smart speed adjustment block, and the auto-start-stop module. Each module has energy saving design for ensuring low energy consumption in the process of sensing and controlling. The smoke detecting module contains a high precision, low power MQ-2 smoke sensor combined with the signal amplifying chip to achieve precise measurement of the concentration level of second-hand smoke. The sensor works in an intermittent mode, minimizing power consumption during inactive time; dust and interference resistant to fit into complex construction site environment. Intelligent speed regulation module working together with the energy saving fan of the purification layer. Built in concentration threshold algorithm, it automatically adjusts fan speed according to the data of the smoke sensor, in low concentration periods, fans run slower; in high concentration periods, they run faster, achieve demand-based speed adjustment, without wasting energy running constantly at full speed^[3].

The auto-start-stop module combines the function of smoke detection and fan control, sets a threshold value of smoke concentration as starting and stopping conditions. Once reaching the threshold of smoke concentration, the purification process is automatic and when the concentration reaches under the safe value, the machine stops automatically without any human intervention which makes this system very convenient for users as well as saves electricity when not in use. All these three modules are controlled by same microcontroller, minimizing the number of redundant components, and maximizing the total energy efficiency.

4.3. Integrated design of lightweight, intelligent, and portable adaptation features

The holistic design of the light-weighted, intelligent, and portable adaptive integration seamlessly blends wearable function and smart purification system together by means of structural optimization and materials light-weighting, the purifier has light-weight, small volume, good wearing properties without reducing the purification effect. practical yet environmentally friendly. The simple and monolithic form reduces its general size as it contains the fan in a small volume, components: filtration parts and intelligent blocks; light-weight, low-carbon materials (e.g., recycling carbon fiber casing and biodegradable silicone wearable) for minimizing the weights and being comfortable, autonomous running. Smart adaptation includes wear-detection and context-aware adaptations: a power-efficient touch sensor on the band goes to sleep if we are not wearing it, greatly reduces the power usage. The scene adaptation option enables predefined sensitivity based on the location of construction, i.e., outdoors or indoors to avoid spurious triggering by ambient noise and improve cleaning performance.

At the same time, to ensure that it can quickly absorb second-hand smoke within its range but not blow directly into the face of builders when they use it, we designed the air cleaner's inlet and outlet in such a way as to allow air flow through 360 degrees around itself, thus achieving both effective cleaning performance and user experience, and realizing the organic combination of mobility and function.

5. Design and implementation of wearable secondhand smoke absorption and purification devices under the dual carbon goals framework

5.1. Selection of low-carbon and environmentally friendly materials for purifier components

The choice and use of low carbon green materials for air purifier parts shall follow “performance suitability, low carbon first and economical rationality”. with differential low-carbon material selected according to the needs of each component. The purifier casing is the main supporting part, uses recycled carbon fiber reinforced bio-based plastics composite material. The latter combines the high strength and light weight, and recyclability, the key low-carbon characteristics, replacing the original high-carbon ABS engineering plastic materials and greatly reducing carbon dioxide emission in its manufacturing process, while providing good impact resistant capability, dust-proof function. The wearing parts adopt food grade biodegradable silicone material, balancing comfort with environment; it degrades after use. The filter assembly has biodegradable plant fiber filters and recycled activated carbon adsorbent layers: the filters degrade after one-off use, while the activated carbon is regenerated from industrial waste and increases the resource utilization rate.

The housing of the intelligent part is made out of recycled polycarbonate material with wear resistance and interference resistance, meets sensor/chip and other component protection requirements; the power supply module housing is fabricated in light weight recycled aluminum alloy, integrates heat conduction function and protection performance so that materials can be recycled to realize full process of low carbon on the component level.

5.2. Integrated application of low-energy consumption technologies in purifier treatment functions

The holistic deployment and use of the low energy technologies in a system for air purifier applications demands to tackle with four main areas: sensing, purification, control, and power supply for overall energy efficiency and low carbon performance; the sense layer includes micro-power sensing technology and signal optimization technology, adopting MEMS microelectromechanical smoke sensor instead of conventional large-power sensor and low-noise signal amplifier technique which improves the sensitivity and reduces power consumption; sensor sleep that supports intermittent sensing and thus additional power savings during the sensing phase; purifier which couples low power blower fans with efficient filters, using brushless dc fan combined with infinitely variable frequency technology to achieve accurate power adjustment; multi-functional filter technology of “filtration-adsorption-decomposition”. Increases the purification efficiency, decreases the fans' high-load work time. The control part implements light-weighted microprocessor technology and a low power algorithm, using low power MCU controller ICs that have simple concentration thresholds built into their

algorithms, which minimize the processing requirements as well as power demand of the sensor's operation ^[4].

The power supply system adopts the characteristics of rapid charging and low energy consumption for batteries as well as the solar assisted power supply technology, it has a high capacity, low self-discharge type rechargeable Li-ion batteries in combination with small size foldable solar panels so that natural daylight on construction site can be used for recharging the batteries thereby leading to effective use of power.

5.3. Establishment of an evaluation system for purifier design with functional and low-carbon synergy

The establishment of the indicator system to evaluate the design schemes of purifiers integrating function and low-carbon is based on "function index, low-carbon index and overall index" in three levels. Each index has a measurable assessment standard, so that the purifier solution scheme can be comprehensively and scientifically evaluated. The functional indexes include the main factors such as purification effect, sensing accuracy, response time, and wear comfort; purification effect meets the requirements of corresponding national standard for air purifier, while certain numerical standards have been set for detection precision, reaction time in order that these instruments' intrinsic decontamination functions satisfy site-specific working demands. Carbon footprint indexes involve such factors as material carbon emission, production energy demand, operation energy demand, and recycling rate: materials carbon emission quantifies carbon emissions of the manufacturing process for components; production energy consumption: the energy consumption of a product during its manufacture, and operational energy consumption: the total life cycle energy consumed. recycling rates reflect recyclability/biodegradability of its constituents, all with well-defined low-carbon boundaries.

Technical, economic, and longevity factors are included in the overall performance measure, balancing the implementation feasibility and usability of the design solution, where the evaluation system adopts a 100-points grading scale. where functional indicator and low-carbon indicator are respectively set as 40 points, and the comprehensive index is set as 20 points. According to the score result, optimize the design solution so that the function and low carbon can be optimally coordinated.

6. Conclusion

Under the guidance of dual carbon goals, taking the wearing type second-hand smoke absorber and purifier as the research object, systematically studies the function design and low carbon combination of intelligent building environment management equipment, clarifying the design requirement of intelligent building environment management equipment in the background of dual carbon, identifies underlying links of the purifier's essential governance functions with low-carbon design, and applies the low-carbon design to its three key functions of adsorption filtration, sensing control, and mobility. Furthermore, this work provides an overview of a possible deployment process including materials, technology application and assessment mechanisms. The study realizes the full fusion between smart management functions and low-carbon concepts, providing concrete and feasible ideas for low-carbon, intelligent design of intelligent construction environment management equipment.

Disclosure statement

The authors declare no conflict of interest.

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