International Journal of Heat and Technology
Vol. 41, No. 1, February, 2023, pp. 46-54
Journal homepage: http://iieta.org/journals/ijht

Beneficial Impacts on Environment and Society Through Smart Sustainable Maintenance of Public Real Estate

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7th AIGE-IIETA Int. Conf. and 16th AIGE Conf.-SPECIAL ISSUE

https://doi.org/10.18280/ijht.410105

Received: 9 January 2023
Accepted: 10 February 2023

Keywords:
energy audit, energy efficiency, life cycle assessment, indoor air quality, sick building syndrome

ABSTRACT

Healthy, sustainable, energy-efficient buildings are more valuable since the green movement. Air quality, lighting, acoustics, and thermal conditions affect IEQ. Indoor air quality affects resident health. Chemicals or organisms contaminate the air. This work contributes to the goal of renovating and decarbonizing existing public administration buildings in the regional territory by integrating technologies and advanced building-plant systems management policies. This work focuses on building-plant energy diagnosis, its principles, regulations, and application procedures, especially IEQ and thermo-hygrometric comfort measurement and evaluation protocols. It follows a discussion of LCA for energy diagnosis and smart indoor air quality management and maintenance, such as quantifying human activity's impact on the indoor environment or adapting a modeling methodology to identify critical parameters to be monitored and controlled by building-plant systems' integrated sensor and actuator architecture. The goal is to find connections between indoor and outdoor air quality, occupant behavior in public buildings (especially schools and universities), and short- and long-term BRI. The study compares smart building diagnostic methods and procedures to European standards. This may improve Public Building Administration Social-LCA standards.

1. INTRODUCTION

Buildings are important locations for us to live, work, and relax. Structures built now are projected to last at least the next 50 years, hence decarbonization of existing buildings is required to help combat climate change. Buildings alone account for over 40% of worldwide energy consumption and 33% of greenhouse gases. According to a recent European Commission research, over 75% of buildings in the EU are not environmentally friendly, with many reliant on fossil fuels for heating and cooling. Similarly, according to the US Energy Information Administration, heating and cooling account for 48% of total energy usage in US residences. The WHO has acknowledged that indoor pollution is a significant environmental risk, with the main causes being, on the one hand, the significant amount of polluting sources present in the rooms, and, on the other, the reduction of ventilation rates, which is generally associated with energy saving reasons. For a long time, the issues of the consequences of indoor pollution have been underestimated in Italy, owing to both difficulty in objectively classifying the illnesses associated with it and a lack of approved techniques for IAQ control [1]. The Indoor Environmental Quality (IEQ) is a prominent issue in the sustainable design community right now since encompasses a variety of aspects such as air quality, lighting, acoustics, and thermal conditions within the structure, all of which have an impact on the health and well-being of the occupants. It relates to the composition of interior air and how healthy it is for building occupants. Air quality issues emerge in buildings when chemical or biological pollutants accumulate to levels that are detrimental to occupant comfort or health. Buildings that reach these levels of pollution are known to have Sick Building Syndrome (SBS), and occupants are at risk of becoming ill as well [2].

The literature emphasizes that while efficiency solutions for new and existing buildings are clearly advanced, the same cannot be said for historic structures, which suffer from a lack of proper interpenetration between efficiency methods and cultural value conservation [3]. Energy simulation software are now the most widely utilized tools for understanding a building's energy performance characteristics. They are used to make design decisions for new buildings as well as retrofit interventions on existing structures.

This work, in particular, consists of a short summary of a wider systematic state of the art of the newest methodologies of the building-plant energy diagnosis, its principles, regulations, and the application procedures, which are particularly related to the identification of the measurement and evaluation protocols of IAQ (Indoor Air Quality) and thermo-hygrometric comfort. It follows a discussion of the utility of Life Cycle Assessment (LCA) for energy diagnosis as well as smart indoor air quality management and maintenance, such as the possibility of quantifying the impact of human activity on the indoor environment or adapting a modelling methodology to identify critical parameters to be monitored and controlled by an integrated sensor and actuator architecture on building-plant systems.

The article is structured as follows: the second paragraph consists in an in-depth analysis of the topic and the procedures for Energy Audit, as well as a focus on modeling and simulation practices; the third paragraph is dedicated to the theme of Indoor Air Quality and its possible interaction with sustainability evaluation methods such as the LCA. This paragraph presents also an excursus on the various integrated design choices amongst the aforementioned issues; the fourth paragraph summarizes the economic and social effects that these issues imply; and lastly, the work ends with concluding considerations.

2. ENERGY AUDIT

Energy audit, or energy diagnosis, is a systematic procedure that identifies energy inefficiencies in buildings based on construction practices, the envelope, and the complex system of technological systems, quantifies the waste that results from it, and proposes technical solutions that allow them to intervene to improve their energy performance [4]. Energy efficiency improvement interventions, and thus the prosecutable savings, can concern the building's envelope or systems, but they can be integrated more readily to provide enhanced outcomes. An energy audit should be regarded the first stage in any energy efficiency project, because it is impossible to suggest significant improvement ideas without a complete understanding of the building's features.

The energy modeling approach to be used will vary depending on the scale of the energy system being examined (global, continent, region, nation, sector), as will local legislation and application processes.

The function of energy efficiency in buildings is obvious and well-defined in European Union (EU) directives: it already comprises measures that must promote both the improvement of energy consumption and the IAQ. To highlight the potential inherent in energy efficiency measures, the EU has committed to clarifying the objective of the interventions through recommendations. The Green Deal has highlighted the importance of building rehabilitation interventions in an even more substantial and effective approach [5].

2.1 Regulations and principles

The Energy Efficiency Directive (2012/27/EU) [6], which went into effect in December 2012, required Member States to define national energy efficiency in order for the EU to meet its major goal of reducing energy consumption by 20% by 2020. Member States were still allowed to impose more stringent minimum measures to encourage energy conservation. The Directive established legally binding rules for end users and energy suppliers; then required Union Member States to publish their national action plans for energy efficiency every three years and required the Union Member States to publish their national action plans for energy efficiency every three years. On the proposal of the European Commission, the European Parliament updated Directive 27/2012 in January 2018, with the motto "Energy efficiency first" as one of the fundamental principles of the Union of Energy, aimed at ensuring a safe, sustainable, competitive, and affordable energy supply in the EU. The Commission suggested an ambitious 30% target for energy efficiency by 2030 in the new directive. Following talks with the Council, an agreement was reached in 2018 that established the goal of lowering primary and final energy consumption by 32.5% by 2030 at the EU level [7]. The regulation also required EU member states to undertake steps to reduce their yearly energy usage by 4.4% on average by 2030.

For the period 2021-2030, each Member State is required to develop a ten-year integrated national plan for energy and climate (PNEC) outlining how it intends to meet its energy efficiency targets for 2030.

In July 2021, the Commission presented a proposal for revision of the Energy Efficiency Directive as part of the package "Making the European Green Deal" in accordance with its new climatic ambition of reducing EU green emissions by at least 55% by 2030 compared to 1990 levels and becoming climatically neutral by 2050. In this regard, he advocated raising the targets for reducing primary and final energy consumption by 2030 by 39% and 36%, respectively, compared to the updated reference figures for 2020. In absolute terms, the approach given requires that the EU's consumption of primary energy and final energy do not exceed 1023 and 787 million tons equivalent oil, respectively, in 2030 [8].

The Commission invites Member States to set indicative national targets for reducing energy consumption, introduces strengthened automatic mechanisms to fill gaps, and doubles the obligation for Member States to achieve new annual energy savings, bringing it to 1.5% of final energy consumption from 2024 to 2030.

At the moment, the following guidelines must be followed in Italy in order to do an energy assessment of a building:

- UNI CEI EN 16247-1: 2012 [9] "Energy diagnosis - Part 1: General requirements", which defines the requirements, methodology and reporting common to all energy diagnoses;
- UNI CEI EN 16247-2: 2014 [10] "Energy diagnosis - Part 2: buildings", which applies to diagnoses specific energy for buildings, defining their requirements, methodology and reporting;
- UNI CEI EN 16247-5: 2015 [11] “Energy diagnosis - Part 5: Energy auditor skills ", which specifies the skills that the REDE must have (referent of the energy diagnosis);
- UNI EN 16798-2:2019 [12]: Energy performance of buildings - Ventilation for buildings - Part 2: Interpretation of the requirements in EN 16798-1 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics;
- UNI/TS 11300 [13] regarding the energy performance of buildings.

UNI/TR 11775:2020 Report [14] specifies the various processes to be taken in order to construct an energy audit. The majority of the activities are the responsibility of the technician in charge of the editing staff. In some phases, the final user's input is also required for accurate modeling of the building capable of accurately depicting the status quo, as well as the definition of intervention hypotheses. The role of the end user is critical for adapting the model to the actual circumstances of usage of the property, since the behavior of persons who live in it determines much of the energy use. The bills of energy and water, the habits of attendance at the property (which establish the employment indices), the ways of controlling thermal systems, and the common services are all important data. The technician in charge will have to interview the building's residents to learn about their living patterns and recommend solutions that match the demands of the user in order to save energy. The phases of the process are:

a) Preliminary requirements: it is intended to provide the parameters that will be included in the offer request. The end user must give the requirements for the delivery of the diagnosis, reporting with a defined purpose and goals, the reference period, the diagnosis boundaries, the assessment criteria, the amount of information necessary, and the timing.

b) Following the assignment of the task to the technician, the roles of the major players, the instrumental resources, the tasks to be performed, and so on must be determined. During this phase, it is required to define in detail the energy performance indicators, the EnPI (Energy Performance Index), which allow the analytical priorities to be identified.

c) Data collection: gathering the information required to assess the true status of the building or its actual consumption. Following the gathering of technical documentation, the accuracy of the gathered data must be validated, as well as the inclusion of those who are missing through reliefs and interviews with inhabitants. It is especially important to have on hand the following information, which are condensed in these macro-chambers of information: general data, geometric data, building methods of use (temporary or continuous use), data building envelope dispersion, external obstructions, shielding of the building; heating system; ventilation system and air treatment; summer cooling system; electrical system; renewable sources plants; Building Automation and Control Systems (BACS), handling components inside buildings, such as elevators, mobile stairs, transporters; thermal comfort, air quality, acoustics, and illumination are all important considerations. In some cases, a check by the technician will be required.

d) Data analysis: all acquired data is evaluated and compared to each other to ensure consistency. The energy performance indicators are used in this phase. EnPIef is computed: effective energy performance indicator computed in accordance with the rules of preliminary requirements.

e) Energy balance development: this is the establishment of an energy model based on data from the energy inventory (IE), with the goal of identifying the list of important consumers for each energy carrier. As a result, an objective performance index or reference index of energy performance exists: it may be a combination of one or more particular indicators linked to important energy uses and separated by typical functional domains. Intervention scenarios are defined: Following the completion of the analyses, the chosen technician will provide a series of scenarios or combinations of possible interventions to suit the clients' expectations. The analyses performed on the specified scenarios must include a technical economic assessment (cost/benefit analysis) in order to offer the customer with information relevant for determining intervention priorities based on technical life. As a result, the intervention priorities must be set based on the energy and economic advantages obtained from the interventions. If there are additional forms of benefits, they must be stated explicitly for each intervention. Although not required by the regulatory method, this step may include a comparison between the technician and the customer to determine which of the identified situations is a priority for the client.

f) Drafting the diagnostic report and the final meeting: beneficial for presenting the diagnosis report to the client and facilitating decision-making. The diagnostic process is deemed formally closed at this meeting, with the signature of the closure report by approval.

2.2 Modelling and simulation

After gathering and evaluating household consumption data, the energy model of the building-system simulation must be built in order to evaluate energy-saving prospects. This model must reflect the building's behavior as accurately as possible, taking into account the relationship between technological systems and building envelope. Regarding the calculation of the energy performance of buildings, it is necessary to define whether to use a stationary method, which provides for simplified calculations on a monthly basis and refers to the technical standards UNI/TS 11300 [13] based on the purpose of diagnosis, the characteristics of the building, and the quality of the input data, or whether to use an hourly dynamic technique, which gives hourly calculations and allows you to account for the system's real operation hours, the fluctuation of the working circumstances, and those to the outline over the day (external temperature, radiation, etc.). It is critical to verify that the computation procedure employed is traceable.

The approach to be utilized is heavily influenced by the goal of the diagnostic, the building's features, and the quality of the incoming data.

The simulated model of the building-plant system, like any digital twin, requires validation: to validate the energy model, it is important to compare real consumption, termed actual consumption (Ce), and model consumption, called operating, in real climatic conditions (Co). To compare the consumption of the energy model with the real ones, the external thermo-hygrometric conditions must be considered, as well as the profiles of usage of the building-plant system throughout the years under consideration. As a result, the temperatures (both exterior and internal) evaluated will be the average of the temperatures of the years studied. The energy model must, in reality, take into account the actual thermo-hygrometric conditions as well as the actual use profiles. The regulation requires that the difference between operational and effective consumption be no more than +/- 5%. The validation of the variance in consumption is therefore provided by Eq. (1):

$$-0.05 \leq \frac{C_o - C_e}{C_e} \leq 0.05 \quad (1)$$

If specific data are not available during the model's creation phase, and depending on the level of detail that has been determined to deliver the energy audit, the maximum deviation margin can be +/- 10%.

Validation is a prerequisite for proceeding. If the model cannot be validated, the data entered and the adjustment variables for real consumption must be reviewed. Once the model has been validated, it is possible to continue modeling the energy efficiency improvements that are intended to be proposed. The evaluation of the improvement actions is carried out through simulation, which is then assessed separately or in combination using energy analysis software. In order to calculate the energy performance of buildings, a quasi-stationary technique can be utilized, which allows for easier monthly calculations and, in Italy, conforms to the UNI/TS 11300 technical requirements [13]. In March 2018 UNI EN ISO 52016 [15] introduced a method of dynamic time calculation that technicians can use for a more accurate evaluation of the energy performance of the building, which takes into account the actual operating time of the system, the variability of the working conditions, and those to the outline during the day (external temperature, radiation, etc.). The energy savings computed for each intervention are then cost-benefit assessed in order to help the client/owner of the building in the selection of solutions [16].

Furthermore, the technological innovation made by Building Information Modeling (BIM) in the construction sector can play a very important role in the Facility Management paradigm [17], because it allows overcoming the limits of the traditional building process in favor of a cyclical process, which allows constant verification and control of the information shared among all building process actors. As Figure 1 shows, multiple tools and applications have been developed to allow to perform energy analysis in the BIM environment with varying outputs and interoperability levels, significantly optimizing the integrated design process towards the Zero Energy Buildings (ZEB) standard with cost reductions across the entire life cycle and quality enhancement.

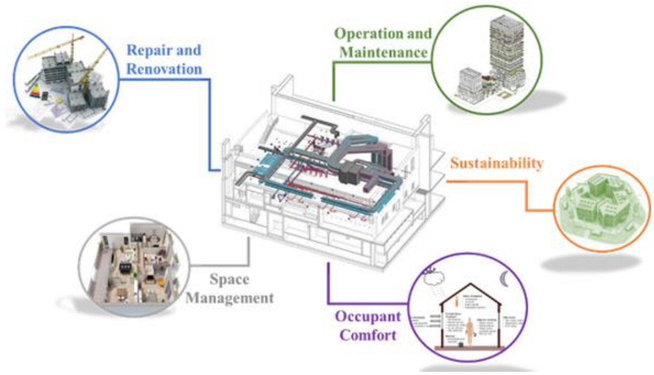

Figure 1. BIM for facility management

Table 1. Pollutants of greatest concern for each source of pollution and their effects on health

Source	Pollutants	Effects on health
Gas or coal combustion processes for heating and/or cooking, fireplaces and wood stoves, vehicle exhaust gases	Products derived from combustion (CO, NO_x, SO_2, Particulate)	Increased occurrence of chronic respiratory symptoms, as well as a possible reduction in ventilatory respiratory function, sensitization thresholds to various allergens may be lowered, a higher risk of developing COPD
Building materials and insulation	Asbestos, synthetic vitreous fibres, particulate matter, radon; organic agents (due to the presence of moisture and/or powder)	Diseases such as asbestosis, mesothelioma and lung cancer, possible pathologies of the intestinal tract and for the larynx
Carpets and coating materials	Formaldehyde, acrylates, VOCs and biological agents (due to the presence of moisture and/or dust)	Possible broncho reactive effects in asthmatic patients
Furnitures	Formaldehyde, VOCs and biological agents (due to the presence of moisture and/or dust)	Possible broncho reactive effects in asthmatic patients
Cleaning products and liquids	Alcohols, phenols, VOCs	Sensory discomfort, effects on many organs or systems, in particular on the central nervous system
Photocopiers	Ozone (O3), toner powder, VOCs	Sensory discomfort, effects on many organs or systems, in particular on the central nervous system, irritative effects on the ocular mucous membranes and the upper airways, coughing, bronco obstructive phenomena and alteration of respiratory function
Cigarette smoke	Polycyclic hydrocarbons, VOC formaldehyde, CO, fine particulate matter	Sensory discomfort, effects on many organs or systems, in particular on the central nervous system, respiratory symptoms, changes in respiratory function, chronic bronchitis, asthma, anginal crisis, headache, confusion, disorientation, dizziness, impaired vision and nausea
Air conditioning systems	CO_2 and VOCs (due to a low number of hourly spare parts or excess recycling), biological agents (due to lack of cleaning and maintenance)	Sensory discomfort, effects on many organs or systems, in particular on the central nervous system, chronic bronchitis, asthma
Dust	Biological agents (as indoor allergens like mites)	Asthma, conjunctivitis, rhinitis and dermatitis
People	CO_2 and biological agents (bacteria, viruses, etc.)	Sensory discomfort, effects on many organs or systems, in particular on the central nervous system, headache, confusion, disorientation, dizziness, impaired vision and nausea
Pets	Indoor allergens (hair etc.)	Asthma, conjunctivitis, rhinitis and dermatitis
Natural hot springs (lava, tuff, granite, etc.)	Radon	Lung diseases such as emphysema, chronic interstitial pneumonia and pulmonary fibrosis

This study on energy diagnosis with BIM methodology is introduced in this field, with the goal of overcoming the limitations that currently remain in information interchange interoperability. Currently, BIM enables for geometric, physical, and thermodynamic modeling to aid in energy diagnostics, as well as the modeling of the overall building system utilizing highly complex features. The energy concerns and related issues are becoming increasingly important in building design. As a result, BEM (Building Energy Modeling) is expanding alongside BIM, and both are describing the design of existing and new buildings. The new contributions to the existing well-established standard modeling lie in the use of particular items to represent the energy efficiency of the project building. Compare the energy performance of the building in the state and the project state dynamically; Use dynamic integration between the calculation and the BIM model (BIM4D) to calculate the costs of energy-saving actions. Display the data on the models so that you can quickly comprehend the performance enhancements of each component and the overall model that depicts the building-plant system. Thanks to the optimization of strategies and choices throughout the life cycle it improves energy performance because it allows a first evaluation of the interventions already in the preliminary design and a more punctual estimate of the energy performance of the building in compliance with the limits required by legislation, but most importantly because it guarantees the preservation of the actual performance values during the use of the building, with an increase in indoor air quality.

At the European level, a standardization program of the BIM Integrated Energy Diagnosis methodologies is already underway, with the Technical Committee of CEN 244 developing a Model View Definition [18] that defines the parameters to be considered for energy performance in collaboration with the CEN /CT 371 Project Committee - Energy Performance of Building Project Group. All of this standardized effort begins with the demands of the primary international players, who determine the need for information sharing in any field and carry out the pre-staring activity.

3. INDOOR AIR QUALITY IN ENERGY AUDIT AND THE ROLE OF LCA

Indoor air quality (IAQ), thermal comfort (thermal quality), lighting quality, and acoustical quality are all examples of IEQ, which can be expanded to include spatial and ergonomic (equipment and furniture) factors in building design and usage. Chemical pollutants such as volatile organic compounds (VOCs) and particulates, as well as biological contaminants such as bacteria, viruses, and fungus, are all part of IAQ. In terms of results, IEQ has been linked to a variety of health and productivity effects on building occupants [19, 20]. Methods for experimentally assessing IEQ impacts may be divided into two categories: single variable correlations between building-related parameters and measured occupant health or performance outcomes, and multivariate indices using single-value or reduced-parameter predictors of occupant outcomes [21].

Taking into account the most important IAQ criteria found in the literature [22]: a) commissioning criteria; b) natural ventilation potential; c) advanced mechanical ventilation; d) moisture control and microbial contamination; e) enhanced local exhaust; f) air distribution; g) air filtering; h) VOC, NOx, CO, and particulates emissions; i) contaminant control; j) radon protection; and k) physical IAQ measurements. And, as illustrated in Table 1, the most serious concerns about poor indoor air quality, it is clear that an in -depth energy diagnosis that takes into account all the illustrated features prior is the best starting point to design different scenarios of redevelopment interventions that take into account the problems of air quality and thermo-hygrometric comfort.

These listed in Table 1 are the symptoms that are often detected during or soon following pollutant exposure, and they are curable, short-lived, and readily eradicated by simply moving away from the source of pollution. The other form of sickness occurs over time when an individual has been exposed to one or more contaminants for an extended length of time or repeatedly. They generally do not appear immediately after exposure, but rather over a period of time, even years, and can have major implications involving the skin (dermatitis), respiratory system (nasopharyngeal tumours, nasal cavities), and cardiovascular system.

This paragraph underlines the absence of attention to IAQ from current sustainable evaluation methodologies through a complete analysis of relevant criteria, in addition to proving that Energy Audit and IAQ criteria are complimentary. For example, the BREEAM, LEED, and Passivhaus standards (qualitative assessment methods) used in UK Real Estate as models to define the principles and applications procedures for an AIQ analysis all ignore fundamental strategies for human health and wellbeing, such as radon prevention, preoccupancy flush, moisture control, garage pollutant protection, combustion venting, and indoor contaminant control [23]. Furthermore, all of the assessment methodologies examined overlook the need of giving IAQ information to building occupants via the building user guide. The importance of post-occupancy assessments, particularly physical IAQ measurement, has also been overlooked.

The world of design and building has always been defined by the cohabitation of a great amount of information of diverse sorts inside the same process. As a result, in the face of a natural increase in the transversal complexity of the essential data, one of the primary goals is that of actual integration across the design disciplines, with the goal of improved control in terms of realization, costs, and transparency.

While LCA is already regarded a strategy to be integrated by early bird design in new buildings [24], integration with techniques for building recovery and restoration is still unknown and has several procedural gaps. Transmittance cannot be regarded as an adequately explanatory metric for defining environmental effect. To utilize transmittance as an indication of environmental effect, one must be conscious of the fact that the real environmental impact of the materials must be appropriately evaluated. LCA is now the only technique that examines the environmental effect from cradle to grave.

The literature on LCA in IAQ has mostly concentrated on adding indoor chemical pollutant intake into the current human health toxicity of LCIA categories [25]. The consequences of indoor pollutant emissions are evaluated using emission rates from interior materials or processes as well as building-level factors like ventilation and occupancy rates. Incorporating IAQ into LCA at the whole-building level may reveal critical design features that are overlooked in traditional LCA, increasing the relevance of LCA to real estate and, eventually, assisting in improving the long-term environmental performance of buildings. For example, Colling et al. [21] developed a methodology for incorporating IEQ impacts into whole-building LCA (dubbed IEQ+DynamicLCA), distinguishing chemical-specific impacts that coincide with standard LCIA categories from non-chemical-specific impacts, and finding any gaps or overlaps. The framework expands the LCA matrix to include three categories of effects: internal chemical impacts, internal non-chemical health impacts, and performance/productivity impacts.

To be comprehensive, preparations have already begun to combine the BIM with the LCA for a holistic diagnostic not only of the building's current status but also of its life cycle. For the sake of brevity, please see the ENEA report on this topic [26].

Finally, LCA may be used as an assessment tool for the decision-making process in sustainable building; nevertheless, it has significant drawbacks that must be addressed before it can be included into the design process. One of the major drawbacks of the Life Cycle Assessment is that it is entirely dependent on the quality and availability of the data submitted, which is sometimes insufficient or wrong, resulting in an inaccurate final rating.

3.1 Integrated design choices

Integrating different methodologies, such as Energy Audit, LCA, and IEQ, adds to the broad-spectrum characterization of important parameters through the use of a thermodynamic-technological model of the dynamic behavior of the building system. It is therefore possible to achieve a balanced balance between energy performance and IAQ. For example, if poisonous finishes and materials are not avoided within, the drive toward increasing degrees of airtightness in buildings might be life threatening. The EPA [27] backs up this point of view, claiming that the air quality in an energy-efficient, airtight home may be worse than in a leaky one owing to the propensity for indoor air contaminants to accumulate. The push for energy efficiency may be accidentally and unknowingly generating hazardous living conditions by causing moisture problems, increasing the usage of toxic materials, lowering ventilation rates, tightening building envelopes, and an over-reliance on complex technologies.

The EN 15251, Criteria for the Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics [28], schematized in figure 2, proposes an approach for the certification of the indoor environment emphasizing how the energy qualification of a building would be meaningless without the simultaneous evaluation of aspects indoor. In a broader sense, however, it can be inferred that the relationship between indoor air quality and energy performance should be related to the choice of the thermal insulation of the building - through the use of materials that are at a low or zero emission of indoor contaminants and the control of condensation phenomena – and plant systems for air conditioning and inside natural or mechanical ventilation.

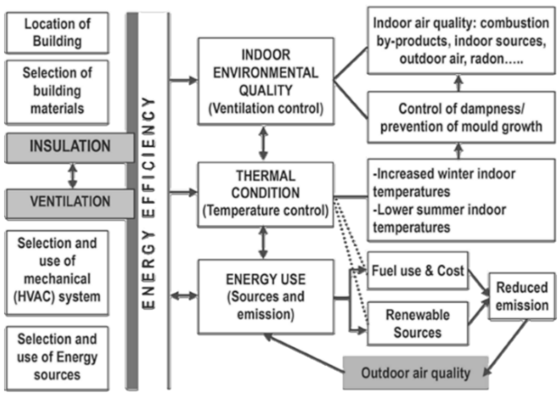

Figure 2. Relation between indoor air quality and energy efficiency

Figure 3, instead, depicts a simple strategy for integrating the LCA with the Energy Audit. A procedure for building diagnostic analysis is essential because it may give input profits for identifying strategies for implementing environmental and energy quality.

Starting with experimentation, at the context level, it is necessary to carry out control actions and pollution mitigation of outdoor pollutants by intervening, particularly on roads, to decongest the areas concerned in terms of vehicular traffic, and by inserting, where possible, natural barriers with polluting substance and noise shielding functions. Regarding the building, it should be noted that interventions on construction, which are now primarily aimed at energy retrofit, cannot ignore aspects relating to IAQ, such as the elimination of degradation factors, such as training condensation and mold, and the use of materials and technical solutions capable of ensuring healthy environments. However, interventions may be classified into two types: those directed at the building envelope to minimize the energy required to maintain thermo-hygrometric comfort conditions in restricted spaces, and those directed at plant components to increase their performance. The majority of envelope options relevant to existing school architecture address the addition of functional layers: coat insulation, with the juxtaposition on the external layer of the perimeter walls of insulating panels made of natural origin, preferred from an eco-sustainability perspective, or the ventilated facade to isolate thermally and protect against summer overheating, ensuring that the envelope's performance is implemented effectively. The selection of strategies to respond to energy instances must therefore necessarily satisfy those of indoor healthiness because this choice is decisive in the control of excess humidity and the resulting microbial growth: in fact, thermal bridges and thermal bridges must be avoided 'infiltration of water? both in the liquid state and in the form of water vapor. In addition to implementing the thermal insulation performance of the exterior surfaces, both transparent and opaque, findings on the acoustic insulation of the envelope are acquired, enhancing overall indoor comfort conditions. The LCA gives thorough information on the emissions of construction materials throughout the whole life cycle, as well as the implications linked to the operating phase of the building's technical systems. The behavioral analysis of the inhabitants, particularly in the usage of services, thus plays a significant role in this integrated approach and should not be disregarded.

In summary, regardless of the strategy that is planned to be taken, the essential needs to be compared for a meaningful study of the building, a multi-crime approach, that is from the standpoint of sustainability, energy, and economic, are:

- Completeness: a precise characterization of the energy system, defined as the capacity to explain the energy system in all of its important features;
- Reliability: appropriate quantity and quality of inspections and in-depth investigations are used to acquire data. The data gathered comprehends both project data and usage data, such as actual consumption. This need can be pursued by building inspections and instrumental reliefs;
- Traceability: the ability to recreate the logical and technical path taken throughout the diagnostic procedure. It consists of identifying the data sources, the techniques for processing the findings, and the work assumptions considered, so that the entire process may be reinforced;
- Utility: a cost-benefit analysis will be used to illustrate the technical-economic evaluation of potential improvement actions. For each intervention scenario, a description, an analysis of the energy and economic benefits, precautions and interactions with other interventions, costs, technical references, regulations and legislative references, and the measures and checks to be carried out downstream of the application will be developed.
- Authenticity: direct and indirect metrics enable verification of the increase in energy efficiency as a result of the suggested interventions.

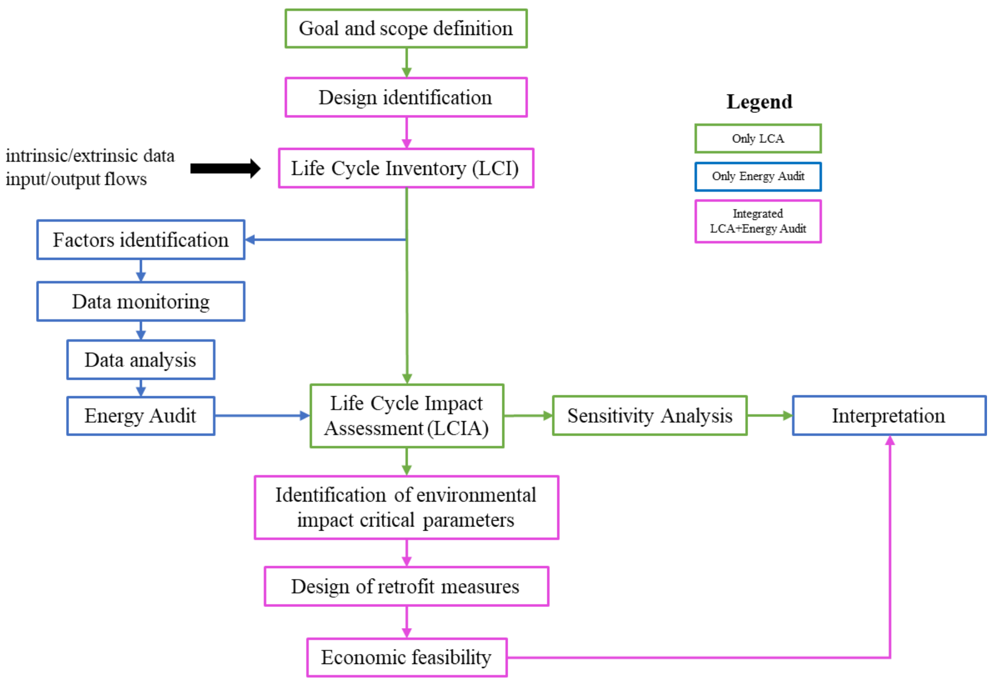

Figure 3. Simplified scheme of an integrated LCA and energy audit procedure

4. SOCIAL IMPACTS OF A BAD BALANCE BETWEEN ENERGY EFFICIENCY AND IAQ: THE SICK BUILDING SYNDROME (SBS)

The health concerns associated with indoor pollution are determined by both the concentration of pollutants in the ambient air and the individual's particular exposure and sensitivity to the latter. Indeed, it has been discovered that the response of individuals to the same pollutant exposure can vary in relation to a number of individual and susceptibility conditions (presence of stress states, specific work pressures, seasonal discomfort); the intensity of the body's response to the irritating effect also depends on microclimatic parameters such as temperature and humidity. The World Health Organization describes SBS as a microclimate reaction that affects the majority of building inhabitants, in some cases 50-60% of the population, and cannot be attributed to a clear cause, such as excessive exposure to a single chemical or a ventilation system breakdown. Sick Building Syndrome was coined in Italy in a 1991 study by the National Commission for the Pollution of Confined Environments to identify a sick building in which the individuals who remain there complain of diseases that might be attributed to the inhalation of air enclosed in it. The SBS is characterized by a stereotyped, non-specific symptomatologic framework, with an uncertain and multifactorial etiology that is most likely related to the current presence, even if in low concentrations, of multiple polluting substances, with no causal relationship to exposure to individual agents. This condition is the source of vexing problems that affect both comforts, with moderate symptoms and particular and specific consequences, as well as the individual's bodily and emotional well-being. These ailments reject the building's roundups and manifest only upon reentry to these situations. The societal effect of indoor pollution may be assessed not only in terms of health, but also in terms of economic expenditures owing to both the cost of healthcare and a more generalized reduction in productivity that is directly related to the environmental discomfort. The increased morbidity in the population caused by indoor pollution has a major financial impact on the community.

Fisk and Rosenfeld [29] estimated that in the United States, potential annual savings and productivity gains from reduced allergic and asthma phenomena associated with indoor air quality could range from $6 billion to $19 billion, including $6 billion to $19 billion from reduced respiratory disease, $1 billion to $4 billion from reduced allergies and asthma, $10 billion to $20 billion from reduced sick building syndrome symptoms, and $12 billion to $125 billion from direct impairing. According to preliminary calculations, the potential financial advantages of enhancing interior environments outweigh the expenditures by a ratio of 18 to 47. Seppänen [30] calculated the yearly cost of poor indoor environmental quality in Finland to be 2.7 billion euros.

In Italy, there are still significant uncertainties relating to similar quantitative assessments, owing primarily to data limitations. In this regard, the Ministry of Health's technical scientific commission on indoor pollution emphasizes the need for more specific information on the levels of exposure of the population to indoor pollution, on the individual hazards to this associate, the proportional expense of the activity’s health treatment, and the economic value to be attributed to the lost years of life. The most recent quantitative assessment of the impact of indoor pollution on population health, published at the end of 2001, the guidelines for the protection and promotion of health in confined environments, indicated a variable amount in the range of 277 441 billion of old people Lire per year, understanding only the healthcare cost linked to pathologies unleashed by allergens, radon, tobacco smoke, C_6H_6, CO. All of the world's health and environmental organizations have now agreed that, for the undeniable benefits to employee health and productivity, IQ management should be completely integrated into production, maintenance methods, and energy conservation in all industrial environments. Unfortunately, even today, despite the fact that attention to the relationship between internal environment and productivity dates back to the early 1990s, the results obtained are mostly lacking, and this is undoubtedly due to the difficult definition of the units of measurement of the parameters inherent in well-being, plant performance, and worker productivity.

5. CONCLUSIONS

The complex theme of interventions on existing buildings has different meanings in the construction sector, which oscillate between conservation and transformation, concerning recovery, maintenance, and redevelopment, with the most important inputs referring primarily to the loss of the original performance levels due to aging or external agents, the functional-spatial adaptation to the new needs of the inhabitants, and the adaptation of energy performance with respect to the intervention on an existing building necessitates a consideration of the sufficiency of traditional methodologies and design tools. In comparison to the present project's complexity and multidisciplinarity, experimenting with new procedures and new technologies that might foreshadow and validate the efficacy of the changes is unavoidable. Although typical system modeling methodologies should be used to estimate energy efficiency, it was demonstrated in the provided scenario that this may be insufficient, resulting in erroneous engineering decisions and extra expenses during the design of the energy retrofit. Only a dynamic modeling simulation with proper turbulence depiction of air flows can provide IAQ data. Integrating conventional and dynamic system modeling simulations is thus advised to achieve the best and most cost-effective balance of thermal comfort, IAQ, and energy efficiency. The transformation of an existing building into an energy-efficient structure, or its energy rehabilitation, cannot be isolated from an accurate study of the building-plant system's factual condition, which allows for the identification of the building's vulnerabilities on which to operate.

Furthermore, there is presently no comprehensive and effective model to aid in the administration of smart monitoring and control systems and to advise the real estate market in terms of IAQ, which is directly connected to human health. The most critical point in the direction of the I4.0 world is the definition and selection of a comprehensive set of parameters, as well as the associated effective control logic of production processes in terms of predictability, leading to an automated improvement of the property's performance from a technological standpoint, including economy, environmental impact, and, last but not least, sociality.

This work demonstrates that integrating the building's energy simulation in a BIM-based workflow will help remove the manual configuration of the energy model, which takes longer and is prone to errors, allowing for a broader use of the building's simulation energy during the entire design phase and beyond. Furthermore, it has the potential to provide documentation and standardization of the simulation model of energy performance, both of which are critical aspects, not only in new projects, but especially in the context of energy redevelopment of existing buildings, where BIM has the potential to make all documentation collected relating to a building during the diagnostic process more easily and accessible. Digitization, in fact, has two major consequences: the modernization of the entire construction process and the realization that in the not-too-distant future, the design of an energy retrofit of a hospital, a skyscraper, or a school can be carried out in any part of the world and made, for example, in Italy. To ensure that projects meet our country's energy-environmental requirements, the software must include the regulatory requirements established at the national level, but you must also ensure that they are not implemented in a regional context, but are aligned with the international context where the standards are defined. Plus, the combination of LCA and energy audits may be utilized to make decisions that take into consideration the system's time-based variations.

To summarize, this work is only a starting point; the overarching goal toward which this work contributes is to renovate and decarbonize existing public administration buildings in the regional territory using a data-driven approach capable of improving energy efficiency and overall comfort through the integration of technologies (Key Enabling Technologies, Internet of Things, Data Analytics) and advanced building-plant systems management policies. The goal is to lay the groundwork for a more comprehensive investigation by detecting patterns and connections between indoor and outdoor air quality, occupant behaviors in public buildings (particularly in schools and universities), and potential building impacts in terms of sustainability and short- and long-term Building Related Illnesses (BRI). The article concludes with a comparison of the identified methodologies and procedures to the requirements for energy diagnostic in accordance with European guidelines to identify and enhance the smart readiness of existing test case buildings. This might be a step forward in terms of improving rules and standards for a broad Social-LCA in public building administration.

ACKNOWLEDGMENT

This research was conducted as part of the IBIS ECO “IoT-based Building Information System for Energy Efficiency & Comfort” project, funded under the ERDF Operational Program 2014-2020 - Action 1B.1.2.2. Public Notice: "Complex Research and Development Projects CORES", Thematic Areas "Energy and Bioeconomy" (CUP G49J19001400004).

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NOMENCLATURE

IEQ	Indoor Environmental Quality
BACS	Building Automation and Control Systems
BEM	Building Energy Modelling
BIM	Building Information Modelling
BRI	Building Related Illnesses
Ce	Actual consumption
Co	Model consumption
COPD	Chronic Obstructive Pulmonary Disease
EnPI	Energy Performance Index
IAQ	Indoor Air Quality
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
PNEC	Plan for energy and climate
VOCs	Volatile Organic Compounds
ZEB	Zero Energy Building