UNIVERSITY OF GÄVLE

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT
Department of Building Engineering, Energy Systems and Sustainability Science

Building Information Modelling for Energy Analysis and Environmental Assessment

The comparison of LEED and Miljöbyggnad for two school buildings in Gävle, Sweden

Sabir Ali

2022

Degree project, Advanced level (Master degree, two years), 30 HE
Energy Systems
Master Programme in Energy Systems

Supervisor: Abolfazl Hayati
Examiner: Hans Wigö

Abstract

The building sector is one of the largest energy consumers and there are global efforts toward sustainable and energy-efficient new buildings and existing buildings retrofit. The application of Building Information Modelling (BIM) in environmental assessment was practiced and studied following the increasing number of projects adopting the BIM workflows and pursuing green building certifications. The interest of this thesis is to study the use of different Building Information Modelling tools used globally for energy and environmental assessment to examine their practical benefits and challenges. Case studies of two primary school buildings that achieved the Swedish Miljöbyggnad system were used to compare what could have been achieved with Leadership in Energy and Environmental Design (LEED) categories of energy and atmosphere and indoor environmental quality to what has been achieved in similar Miljöbyggnad areas. A review and summary of energy and atmosphere and indoor environmental categories in the LEED version 4 user's guide is presented to evaluate the case study potential score in them.

The early adoption of modeling in the evaluation from the conceptual design is the best approach to achieve better performance. It will improve the way of working and result in a more efficient and sustainable building.

The Building Information Modelling software can be used directly in assessment using the integrated modules within the popular authoring tools such as Revit's lighting and Insight the cloud base service or by transferring the model data to a stand-alone tool like IDA-ICE. The energy plug-ins of the authoring tools such as Revit are still lacking full control over the analytical model and the limited input options.

The identified and discussed advantages of Building Information Modelling implementation are collaboration, accuracy, time, and cost saving. Data exchange issues, knowledge, and the differences in assessment tools were discussed as implementation barriers.

Although the full comparison of certification systems is difficult, the comparison between the potential LEED score and achieved Miljöbyggnad rating showed some differences and similarities in the rating systems. The comparison requires rearranging the rating system indicators into unified categories. The framework that compares the scope, structure, content, and aggregation, would give a meaningful comparison. The way that the LEED and Miljöbyggnad are rewarding the indicators and the aggregation of aspects towards the final rating are totally different.

Keywords:

Building Information Modelling (BIM), Building Environmental Assessment Tools (BEATs), Leadership in Energy and Environmental Design (LEED), Miljöbyggnad

Preface

To my parents.

I would like to thank my wife and my extended family for their continuous support during this thesis preparation period and throughout the whole time that I took studying the program.

I am extending many thanks to all the program instructors and my special thanks to my supervisor Dr. Abolfazl Hayati for his guidance and patience.

Nomenclature

Abbreviations and Acronyms

Letters	Description
BIM	Building Information Modelling
LOD	Level of Development
IDA-ICE	IDA Indoor Climate and Energy (Analysis software by EQUA)
IFC	Industry Foundation Class
GHG	Green House Gas
PPM	Parts Per Million
DVUT	Dimensioning Winter Outdoor Temperature
BEAT	Building Environmental Assessment Tool
LEED	Leadership in Energy and Environmental Design
LEED BD+C	LEED for Building Design and Construction
USGBC	U.S. Green Building Council
SGBC	Sweden Green Building Council
EAp	Energy and Atmosphere prerequisite
EAc	Energy and Atmosphere credit
EQp	Indoor Environmental Quality prerequisite
EQc	Indoor Environmental Quality credit
CxA	Commissioning Authority
DR	Demand response
PMV	Predicted Mean Vote
PPD	Predicted Percentage of dissatisfied
sDA	Spatial Daylight Autonomy
ASE	Annual Sunlight Exposure

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1 Introduction

1.1 Background

The expanding Building Information Modelling (BIM) use in Architecture, Engineering and Construction (AEC) industry to digitize and exchange the design and analysis of buildings and infrastructure projects information, created a great interest in its use in all project phases. This expansion of BIM usage has been realized in research. Although most of the resources were focused on BIM use in overall construction planning, design, construction and operation, some publications were focusing more on design and energy efficiency with not enough emphasis on integrating energy analysis and avoiding repeating the task of data entry of already available data in the developed BIM model (Kamel & Memari, 2019).

Addressing the complex sustainability issues in buildings and construction with novel digitalized design methods make it easier than using conventional methods such as CAD (Zhang, Chu, & Song, 2020). The collaborative digital solution in BIM facilitates teamwork for better coordination between architects, engineers, contractors, and facility managers. It provides access to a collective system, a comprehensive model and accurate data exchange that includes the details of the design, specifications, plans and costs (Love, Edwards, Han, & Goh, 2011).

BIM tools are used to analyze the energy and environmental impact of construction projects and produce the necessary documentation to fulfil the requirements of regulations, audits, and certification with Building Environmental Assessment Tools (BEATs). An architectural BIM model with the suitable level of detail can facilitate information exchange and coordination by providing the requirements of sustainability to save time, improve documentation quality and enhance the coordination of project delivery activities towards sustainability and environmental certification.

Building Environmental Assessment Tools are the rating systems used globally to transform the market and promote sustainable practices in construction for the greater good of the natural environment conservation and combating climate change. Miljöbyggnad is the national widely used Swedish rating system to assess and certify buildings' performance. Leadership in Energy and Environmental Design (LEED) is a popular tool that originated in the United States and is used in many regions around the world for the same purpose. The interest is to study the use of different BIM tools used globally for energy and environmental assessment to examine their practical benefits and challenges of their use in case studies of two primary school buildings that achieved the Swedish Miljöbyggnad system and to compare what could have been achieved with LEED categories of energy and atmosphere and indoor environmental quality to what has been achieved in the similar Miljöbyggnad categories of energy and indoor environment.

1.2 Literature review

A search was conducted for previous studies and scientific articles about how BIM is used in environmental assessment, certification process and energy analysis. The reviewed articles were selected by focusing on articles include the energy and indoor environmental quality with case studies. For both energy analysis and BEATs recent articles were selected. The search was conducted using University of Gävle online library searchable databases and Google Scholar. Keywords such as "BIM environmental assessment" and "BIM energy analysis" were used. The keywords "tools" and "case study" were added. Results were narrowed down by selecting articles with case studies.

1.2.1 Previous studies on BIM use for energy analysis:

Energy-related aspects are important in buildings' environmental assessment systems and constitute a large part of the compensation structure in terms of rating points toward the final grade. Different aspects of performing energy analysis using Building Information Modelling (BIM) were discussed in the reviewed articles.

The reviewed articles presented in Table 1 shows that studies were carried out in different climates and geographical areas from Mexico (Vergas & Hamui, 2021) and the USA (O'Donnell, 2013) to China and Taiwan (Lin, Chang, & Lin, 2019; Guo & Wei, 2016), Europe (Galiano-Garrigós, Garcia-Figueroa, Rizo-Maestere, & González-Avilés, 2019; Galiano-Garrigós, Domenech-Mataix, González-Avilés, & Rizo-Maestre, 2021; Antón, Palomar, Consuegra, Alnso, & Oteiza, 2019; Ugliotti, Dellosta, & Osello, 2016; Bonomolo, Di Lisi, & Leone, 2021) and the middle east (Bahdad, et al., 2021; Hamida, et al., 2021). Different building types were studied in the articles with 5 of the 11 cases being residential buildings, 4 educational facilities, a public library and one commercial market. The existence of educational buildings within the researcher's institution makes them suitable for studies with their different type of occupancy, special purpose activities and operation schedules. The confidentiality of information limits the researcher's access to study cases from different types of buildings unless it is under a collaboration agreement with an outside entity. Even in that case, availing the information to the public would be limited in most cases.

Autodesk Revit was found to be the most used BIM authoring tool used to generate the BIM model. Autodesk's domination of the market was obvious since the launch of the famous drafting tool AutoCAD. For a long time, AutoCAD has been the default drafting and documentation tool in the AEC industry for buildings and infrastructure projects. The familiarity of the industry with AutoCAD might be the reason for the wide adoption of Autodesk software tools. Another reason might be the availability of a free license of a fully functional current version for students and educational purposes.

TABLE 1: BIM FOR ENERGY ANALYSIS SELECTED STUDIES

Study	Model generating Tool	Energy Analysis Tool	Case	Location
(Bahdad, et al., 2021)	Revit	DesignBuilder/EnergyPlus	Residential building	Yemen
(Galiano-Garrigós, et al., 2019)	Revit	Green Building Studio / Sefaira / DesignBuilder / IES VE / HULC	Detached House	Spain
(Lin, et al., 2019)	Revit	IES VE	Public retail market	China
(Galiano-Garrigós, et al., 2021)	Revit	Cypetherm HE Plus / DesignBuilder	School building, Lecture Hall and Research lab	Spain
(Vergas & Hamui, 2021)	DesignBuilder	DesignBuilder	Attached Home	Mexico
(Antón, et al., 2019)	Revit	DesignBuilder	Multi-story apartment Building	Spain
(Ugliotti, et al., 2016)	Revit	Ediclima	Library	Italy
(Guo & Wei, 2016)	eQuest	eQUEST, DesignBuilder, and Vasari	University research building	Taiwan
(Hamida, et al., 2021)	Revit	DesignBuilder	University Building	KSA
(O'Donnell, 2013)	Archicad	EnergyPlus	Research building	USA
(Bonomolo, et al., 2021)	Archicad	Ecodesigner plug-in	Apartment building	Italy
(Gonzalez-Caseres, et al., 2022)	Revit	DesignBuilder	Apartment building	Norway

From Table 1, DesignBuilder was the most frequently used performance analysis program in 8 out of the 12 studies. EnergyPlus is the calculation engine for DesignBuilder which makes it the most used software in the reviewed articles. EnergyPlus popularity be because of its availability for researcher as an open source developed by the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) and appeared in their published work.

One major challenge of implementation of energy analysis in a BIM workflow is the data exchange process between the software tools which lacks standardization. Four articles (Bonomolo, et al., 2021; O'Donnell, 2013; Antón, et al., 2019; Ugliotti, et al., 2016) discussed the import of the BIM model into the performance analysis tools and software interoperability. The inability of the stand-alone performance software to provide feedback through exporting the analysis results back to the BIM authoring program was mentioned by (Antón, et al., 2019) Their point, about analysis result feedback, is a good one and would complement the BIM model with energy and comfort details. It will allow the BIM model to be the single source of information and would enhance the workflow of the documentation and project management. The BIM model could then be at the highest Level of Development (LOD), and its functionality can be extended to the building operation and maintenance.

In Norway, which is a similar climate to Sweden, a recent study (Gonzalez-Caseres, et al., 2022), studied an approach to digitize the energy certification system in existing residential buildings. The study discussed the building inspection by generating a BIM model utilizing 3D scanning and perform an energy audit with thermal imaging and smart meters data then use energy simulation for calibration to suggest improvements and cost-effective measures throughout the building lifecycle.

1.2.2 Studies used BIM in BEATs:

Implementation of BIM for sustainability analysis and environmental certification was discussed in many studies from simulation in performance evaluation credits to suggestions of whole workflows and frameworks. The reviewed studies included case studies from different geographical regions in the design phase and in existing buildings. Revit was the most used BIM software in the studies.

Table 2 shows the description of the articles reviewed. A noticeable finding from the table is that LEED is the most used environmental assessment tool in association with BIM in recent research.

TABLE 2: SELECTED STUDIES FOR BIM IN BEATS

	BIM tool	Study description
(Guo, et al., 2021)	Revit	Propose a framework for combining BIM with green building analysis and evaluate performance aspects i.e., the main building, the building envelope, the heating, ventilation, and air conditioning (HVAC), the lighting and equipment. A case in CASBEE rating.
(Romano & Riediger, 2019)		study the viability of using BIM in the process of certification of energy category in LEED, BREEAM and DGNB for new projects using as a case study the building EUREF HAUS 12 – 13 located in Berlin - Germany.
(Ur Rahman, et al., 2022)	Revit	A BIM approach to Evaluate design discissions in a multi-family building using LEED system
(Jalaei, et al., 2020)	Revit	Evaluate the implementation of BIM with a model that automates the process to identify the required number of points based on selected LEED certification categories, accumulates the total selected points as well as suggests the qualified certification
(Kang, 2020)	Revit/Insight	proposed a rule-based evaluation method with BIM linkage to improves the variance and reuse of the evaluation procedure compared to the existing manual evaluation method.
(Rahman, et al., 2021)	Revit/GBS	Performance simulation and cost estimation of different scenarios of LEED certification process for a prototype 3D model was developed by BIM technology for LEED certification.
(Ryu & Park, 2016)	Revit	Proposed an improved geometry verification process to productivity and reliability of energy simulation for LEED.
(Alwan, et al., 2015)	Revit/IES	Undertake an environmental assessment with LEED for a virtual design model in the concept phase.

The integration of BIM into the levels of several green building certifications systems, specifically LEED, BREEAM and DGNB, was discussed by (Romano & Riediger, 2019). The study investigated the data types that can be available in a BIM model and how is it related to certification requirements. That looks like the right direction to enhance the BIM capability in facilitating the evaluation and reporting of indicators' requirements. The developer of BIM software could benefit from such studies to extend their tools' capabilities for a better sustainable design.

Energy analysis, with both integrated tools and stand-alone, has been discussed in all the articles reviewed. The study (Ryu & Park, 2016) addressed an important issue of geometry verification during exporting data to an external program. Model quality checkers are widely used to verify and prepare the analytical model. Model checkers can edit the exported file without the need to correct and reexport from the authoring tool. Such model quality checkers are provided online with some having an automated procedure to prepare the file for certain analysis programs. This verification procedure became part of the BIM workflow when using a third-party analysis tool.

A general framework for to increasing the accuracy and effectiveness of green building performance aspects in renovation projects was presented by (Guo, et al., 2021). The study categorized the building elements and systems as first-level indicators to map them to rating system indicators at a second level. The Japanese certification system, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) was demonstrated with the proposed framework, but it could be applied to other existing building rating systems with the mentioned evaluation and optimization steps.

Some studies proposed methods to automate the LEED process within BIM software. (Jalaei, et al., 2020) presented a data mining Revit plug-in that can predict LEED score evaluation based on the model data and additional user input. The method can be a good way of planning and aiming for credits points and overall rating, but it does not fully support the documentation requirement. Concentration on the essential details is needed for documentation and verification of compliance. Methods involving an integrated solution to the authoring tool could be the best approach considering the increased use and availability of programing means developed to manage BIM and its database. (Kang, 2020) proposed a rule-based framework suitable for multiple platforms by extracting model information in the green building extensible markup language file format (gbXML). The framework was tested for some credits in only one building model and might have some data integrity with extracted data. More testing is needed for such methods to be more developed for application in credit evaluation as the nature of certification is rule-based.

(Ur Rahman, et al., 2022) used a BIM model to evaluate the highly weighed credits by running the simulation in Green Building Studio (GBS) and Insight and comparing the results. Autodesk GBS has been discontinued and is no longer updated with some functionalities not working at all. Autodesk advises users to use the Insight tool.

Adoption of environmental assessment aspects in the early design phase is advantageous. The process can be started from the early phase of the conceptual model provided by BIM. (Alwan, et al., 2015) provided an example of a conceptual model plan to target LEED certification. The study just highlighted the possibility and advantage of early planning, but no specific credit details were presented. The significant reduction of lifecycle cost by sustainability evaluation in the early design stage was highlighted in (Rahman, et al., 2021).

1.3 Aims

An aim of this thesis is to review the current state and the futuristic innovations to extend the abilities of BIM use for sustainability with some of the available BIM tools that are used for energy analysis and environmental assessment and their uses for building certifications such as LEED.

A second aim is to investigate the perceived motivations and challenges that face the adoption of BIM in practice for energy and indoor environment in the environmental assessment and certification.

The third aim is to examine what score could have been achieved in LEED energy and indoor environment indicators for certified Miljöbyggnad cases and compare both certification requirements for those indicators.

1.4 Approach

Case study analysis was performed in two cases of two school buildings. The cases were used to go through the requirements of the energy and indoor environment quality in the LEED rating system. BIM models were developed and used to find out how BIM tools can assist in the certification process.

A review of previous studies conducted about the subject by searching for authentic and quality literature in sources that includes peer-reviewed scientific articles, research and document or reports from professional, industrial, or governmental organizations. The revision and summary of the USGBC user's guide for LEED v4 Building Design and construction (LEED v4 BD+C) was necessary to evaluate the potential LEED score of the cases.

2 Theory

2.1 Building Information Modeling (BIM)

Many definitions were found in literature throughout its development since the technology's inception decades ago. (Kubba, 2017) mentioned the difficulty of determining who brought up the term BIM while there were several companies contributed to BIM development, but many authors believe that Autodesk is the first to use the term and was later accepted by Bentley and other authors believe it is Graphisoft with their software Archicad and the term Virtual Building. (Autodesk, 2022) defined BIM as:

> *"The holistic process of creating and managing information for a built asset. Based on an intelligent model and enabled by a cloud platform, BIM integrates structured, multi-disciplinary data to produce a digital representation of an asset across its lifecycle, from planning and design to construction and operations".*

ISO defined BIM as:

> *"The use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions"* (ISO, 2018).

BIM was defined by the U.S. National BIM Standard (NBIMS-US) as:

> *"a digital representation of the physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition"* (NIBS, 2021).

These definitions distinguish BIM from CAD by not being just a graphical representation of the building elements but model elements graphically and including their properties and relation to each other.

2.1.1 The Dimensions of BIM

Dimension is the meaning of the "D" in BIM and is used to indicate the process and information capacity as in the standard 2D and 3D for graphical representation. BIM went beyond 3D and geometrical visualization with time added as the fourth dimension and cost as the fifth. The terminology has been expanded to become *n*D for multidimensional with more applications and functionalities being described as dimensions (Ding, et al., 2014). Dimensions after the fifth are controversial among vendors and practitioners.

As the model continues to mature to include other uses such as lifecycle analysis, energy, procurement, safety, contract information, cost management and quality each was claimed to be the sixth dimension. Sustainability evaluation and facility management were claimed as the seventh dimension (Wong & Zhau, 2015), while the accident prevention was claimed to be the eighth dimension (Kamardeen, 2010).

BIM is a symbolic representation and dimension is a symbol property. For conceptual and operational clarity, the dimension should be a primary property of the symbol that represents a building component and not a derivative to be considered as a dimension, which was the basis of the idea that BIM can only have four dimensions "4D" (Koutamanis, 2020). Some experts rejected the addition of the newly added virtual dimensions (Bouška, 2016).

2.1.2 Level of Development (LOD)

BIM Level of Development (LOD) is an industry-standard reference specifying the reliability and clarity of the information delivered by a BIM model for each development stage (BIMforum, 2022). The basic definition was created by the American Institute of Architects (AIA) for the AIA G202-2013 Building Information Modeling document as part of a series of digital practice documents. The standard defined the refinement of the model by classifying LOD according to model elements content requirements, authorized use, cost estimation, scheduling and coordination to LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500 (AIA, 2013). Figure 1 shows the mapping of LOD to the construction project lifecycle.

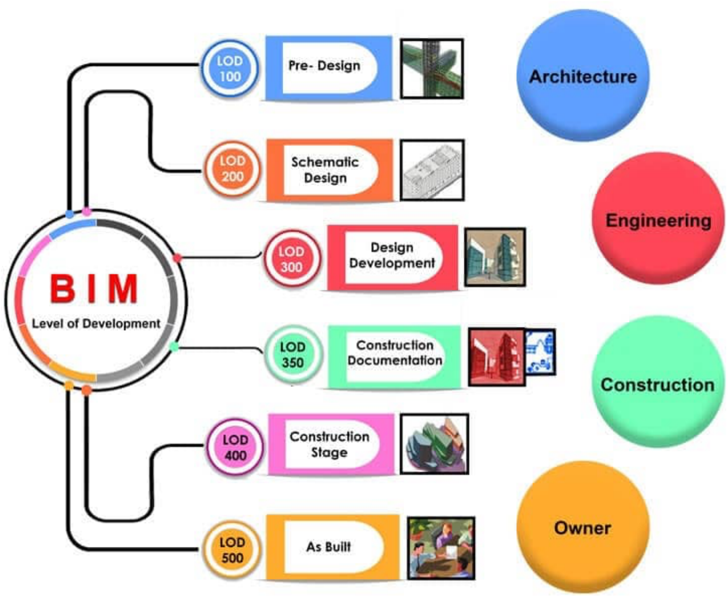

FIGURE 1: BIM LEVEL OF DEVELOPMENT. (SOURCE: (SRINSOFT, 2020))

2.1.3 BIM software

There is several BIM authoring software in the market such as Archicad by Graphisoft, Revit by Autodesk, Microstation by Bentley Systems and Vectorworks by Nemetschek. These authoring tools are the Graphical User Interface (GUI) used to generate and manage a building parametrical geometry model represented with coordinated 2D plan views and 3D views. The programs create a relational database of the input information of the modelled building components. Some of these programs have the capability to perform some engineering analysis utilizing simulation engines. Revit and Archicad are considered the most popular and widely used BIM software. Revit has more user base because of its full compatibility with other Autodesk products and especially AutoCAD which dominated CAD for a long time. Both Revit and Archicad have their modules for energy analysis (Bonomolo, et al., 2021).

2.1.4 Building Energy Modelling and Simulation

In a continuous endeavor to reduce building's energy use and the associated Green House Gas (GHG) emissions, using a conceptual model to simulate and calculate them was a handy using computer-based data models. A conceptual model can be created with the input of required building data: geometry and special data, physical properties such as U-value, heat capacity and density, HVAC type, equipment and operation schedules and occupant's behavior. Computer simulation can be done by defining the output type related to energy use with a numerical approach and mathematical equations representing the physical asset. With accurate input, software simulation approaches can simulate and calculate energy cost, emissions, and occupant comfort (Malhotra, et al., 2022).

2.2 Building Environmental Assessment Tools (BEATs)

Since the consequences of construction and operation of building on the environment have been realized, the industry has been working to define and measure those impacts. Building Environmental Assessment Tools (BEATs) are one result of the work during the last decades to standardize the way of defining, measuring, and evaluating building performance and sustainability (Wallhagen, et al., 2013). British Research Establishment (BRE) in the UK started to work on British Research Establishment Environmental Assessment Method (BREEAM) in 1988 and launched it in 1990 followed by Leadership in Energy and Environmental Design (LEED) in the United States in 1998. Different tools were developed around the world for example the DGNB certification system in Germany by the German Sustainable Building Council in 2009, the Comprehensive Assessment System for Built Environment

Efficiency (CASBEE) by Japan Sustainable Building Consortium (JSBC) in 2001 and the Miljöbyggnad system by Sweden Green Building Council (SGBC) in 2011. These certifications keep developing and updated by their managing organizations with enhanced versions and schemas for different types of buildings. Although BEATs differ in their scope, structure, contents, weighting, and evaluation process, they all embrace the same categories and approaches (Nag, 2019). The differences also reflect the tool country's current priorities and demands.

Because BEATs developed in different regions of the world are focusing on issues that are important for the green building concept in those regions, they differ from each other in several ways. (Wallhagen, et al., 2013) suggested a generic framework to compare the tools in four steps: structure, content, aggregation, and scope. They divided the assessed aspects in the contents into three types: 1) Procedure: when a specific process is described to be accredited. 2) Feature: when a specific equipment or technical solution is assessed). 3) Performance: when the quantitative results from a technical solution are assessed.

2.2.1 LEED

Leadership in Energy and Environmental Design (LEED) is a rating and certification system that supports the design, construction, and operation of buildings to reduce the environmental effect and achieve higher performance and human wellbeing in green buildings. the developer, U.S. Green Building Council (USGBC), claimed that LEED is the most used and popular tool globally and it became a symbol of sustainability and leadership (USGBC, 2022). Green building councils were established in many countries around the world to support LEED and provision has been made to the system to accommodate the regional differences and priorities. The latest version, LEED v4 has been launched late in 2013. The current version was updated in 2019 with an incremental update to be named v4.1 and it was not a full version change.

LEED is rewarding projects by crediting compliance with the accepted codes and standards and exceeding them. LEED Technical Advisory Committees was responsible for points allocation in early LEED versions. To improve the process of how to measure what should be achieved by a project, USGBC has defined LEED impact categories that address USGBC sustainability goals. The impact categories are: reversing contribution to global climate change, enhancement of individual human health and well-being, protecting and restoring water resources, protecting, enhancing and restoring biodiversity and ecosystem services, promoting sustainable and regenerative material resources cycles, building a greener economy, enhancement of social equity, environmental justice, and community quality of life.

By weighting and analyzing those categories statistically as a method of quantification, a weighting system was introduced with LEED 2009 version. LEED rating system has points allocated for the mandatory strategies called prerequisites and optional strategies called credits that address six main credit categories: Transportation (LT), Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), and Indoor Environmental Quality (EQ).

Additional points were allocated for the Innovation (IN) and Regional Priorities (RP) categories. One point was allocated for Integrative Design Process as the main prerequisite for certification. The aggregated total of the pursued credits should be at least 40 points to be certified. Higher certification levels would be awarded for a higher score: 40 points for LEED Certified, 50 points for LEED Silver, 60 points for LEED Gold, and 80 points for LEED Platinum.

The number of points for each credit is determined by the outcome weight of associating credits to the LEED impact category. For this process to be meaningful LEED v4 went on to develop a clear definition of impact categories by breaking them down into defined and bounded components known as key indicators. Credits were associated and evaluated with the seven impact key indicators for points allocation for producing a clean scorecard to be used to aggregate project points (USGBC, 2013). Figure 2 illustrate credits evaluation. Table 3 shows the LEED BD+C score card with credits, categories, and possible points.

USGBC publish documents that provides alternative compliance paths for international projects outside the U.S. such as LEED v4 BD+C Alternative Compliance Paths for Europe (USGBC, 2016).

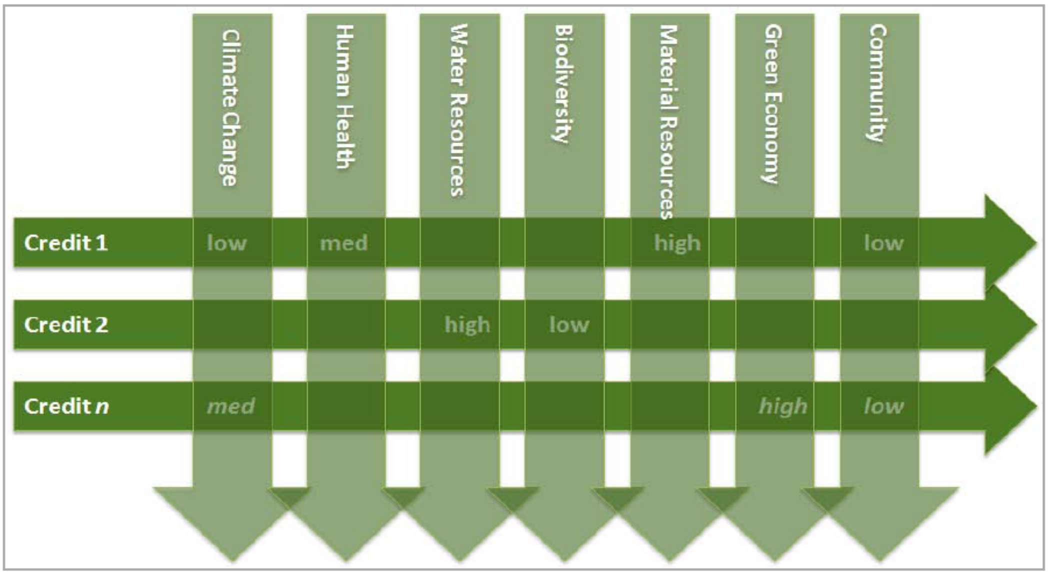

FIGURE 2: AN ILLUSTRATION OF HOW THE IMPACT CATEGORIES ARE USED TO EVALUATE EACH CREDIT IN THE RATING SYSTEM. SOURCE: (USGBC, 2013)

TABLE 3: LEED BD+C V4 SCHOOLS SCORECARD

LEED v4 for BD+C: Schools
Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1
0	0	0	**Location and Transportation**		**15**
			Credit	LEED for Neighborhood Development Location	15
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	4
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1
0	0	0	**Sustainable Sites**		**12**
Y			Prereq	Construction Activity Pollution Prevention	Required
Y			Prereq	Environmental Site Assessment	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
			Credit	Site Master Plan	1
			Credit	Joint Use of Facilities	1
0	0	0	**Water Efficiency**		**12**
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	7
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1
0	0	0	**Energy and Atmosphere**		**31**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	16
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

Y	?	N			
0	0	0	**Materials and Resources**		**13**
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental ProductDecla	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2
0	0	0	**Indoor Environmental Quality**		**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
Y			Prereq	Minimum Acoustic Performance	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1
0	0	0	**Innovation**		**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	0	0	**Regional Priority**		**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0	**TOTALS**	Possible Points:	**110**

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

2.2.2 Miljöbyggnad

Miljöbyggnad is the Swedish system for building performance and environmental assessment and certification. The system was developed by the Sweden Green Building Council (SGBC) which provides other certification tools like BREEAM-SE, GreenBuilding and LEED to create more value for clients and act as an independent third-part reviewer and certifying body for Miljöbyggnad. The tool deals with fifteen indicators across three areas: Energy, indoor environment, and material. Indicators get rewarded with three levels Bronze, Silver and Gold ratings. Miljöbyggnad's rating criteria Aggregates the indicators rating for the final grade. Bronze is the first level, which requires verification of compliance with the building's current regulations and recommendations. Silver rating is rewarded to projects that show more engagement in the environmental issues and exceed the regulatory requirement. The most ambitious projects that meet higher requirements would be rewarded with Gold as the highest level that aims for a better indoor environment verified with measurement or occupant's questionnaire (Sweden Green Building Council, 2021). For existing buildings, the indicators are 16, with the "removing toxic materials" indicator added to the material area. Indicators are grouped as aspects and classified as areas. Indicators and sample results of rating are shown in Table 4. The final aggregated rating can be one label above the worst if most indicators are above. The Gold rating cannot be achieved if any separate rating is Bronze.

TABLE 4: MILJÖBYGGNAD INDICATORS AND RATING AGGREGATION SCORECARD

Nyproducerad byggnad
Miljöbyggnad 3

Byggnad
Kommentar

			Indikator	Aspekt	Område	Byggnad
Energi	1	Värmeeffektbehov	SILVER	SILVER	SILVER	BRONS
	2	Solvärmelast	GULD			
	3	Energianvändning	BRONS	BRONS		
	4	Andel förnybar energi	SILVER	SILVER		
Innemiljö	5	Ljud	GULD	GULD	BRONS	
	6	Radon	BRONS	BRONS		
	7	Ventilation	SILVER			
	8	Fuktsäkerhet	BRONS	BRONS		
	9	Termiskt klimat vinter	BRONS	BRONS		
	10	Termiskt klimat sommar	SILVER			
	11	Dagsljus	GULD	GULD		
	12	Legionella	BRONS	BRONS		
Material	13	Loggbok med byggvaror	SILVER	SILVER	SILVER	
	14	Utfasning av farliga ämnen	GULD	GULD		
	15	Stommen och grundens klimatpåverkan	BRONS	BRONS		

SGBC offers certification for single homes, multi-family apartment buildings and commercial non-residential buildings. Miljöbyggnad user manuals and detailed guidelines are available from SGBC for new construction as well as for existing buildings. The current system generation is Miljöbyggnad 3.0, version 3.2 was the latest update. Local Swedish regulations are required to fulfil Miljöbyggnad's rating requirements such as building regulations and general recommendations from the Housing and Urban Development Authority (Boverket Byggregler (BBR)), Work Environment Authority (Arbetsmiljöverket), Radiation Safety Authority (Strålsäkerhetsmyndigheten), National Board of Health and Welfare (Socialstyrelsen) and other industry standards.

Miljöbyggnad system consists of three areas which are energy, indoor environment, and materials. The rating criteria are different for residential and commercial buildings. The energy area is divided into the energy use aspect, the share of renewable energy aspect and other aspect that include heat power demand and solar heat load. Heat demand assessment criteria is the heat demand calculated as the sum of heat output from the transmission, ventilation, and air leakage per square meter of the surface area of the building's envelope (A_{om}) in $W/m^2.A_{om}$ at DVUT when. This is then rated by comparing it to the assessment criteria, which is compared with the Swedish National Board of Housing, Building and Planning (Boverket) geographic adjustment factor (F_{geo}). Solar heat indicator is rewarding the limit of power requirement for comfort cooling during summer by assessing the heat load in W/m^2 floor area of the East (90^o) and West (270^o) facing windows. The energy use indicator is assessing the building's energy performance by comparing the building's annual energy use in $kWh/m^2.A_{temp}$ to Boverket's Building Regulations and its amendments where A_{temp} is the interior area which is heated to more than 10°C. Energy use is calculated by the delivered energy including heating, domestic hot water, comfort cooling and facility energy. The household and other functions' energy is not included. Internal heat gain of not more than 50 kWh/m^2A_{temp} may be utilized in calculations. The renewable energy indicator is rewarding the building with how much renewable energy of the total annual energy supplied (SGBC, 2015).

The indoor environment area consists of eight indicators. The sound indicator is rewarding buildings for good acoustics design and sound environment by assessing four parameters: the sound from outdoors installations, airborne sound insulation, stage sound and insulation from outside noise. The rating system compares these parameters with BBR and SS 25367 requirements for residential buildings. The year Radon levels must be measured according to the Sweden Radiation Safety Authority's method and buildings are rated according to the measured levels. The Ventilation indicator is rating the building according to the minimum requirements of BBR of 0.35 $l/s.m^2$ outdoor air and the provisioning of the additional exhaust will be rated with Silver and Gold for adding wet rooms exhaust. The rating is different for commercial and residential buildings. In commercial buildings, ventilation per person and air quality (PPM) level are considered. The moisture safety indicator demands meeting BBR requirements and rewarding the involvement of a moisture expert in the project. There are two thermal comfort indicators. Winter thermal comfort requires meeting a predicted percentage of dissatisfied (PPD) of less than or equal to 15% and 20% for non-residential buildings at the corrected design temperature (DVUT). For the silver rating, the indoor thermal climate should reduce the PPM at DVUT. The gold rating for thermal climate winter must meet the conditions for silver rating plus occupant satisfaction survey or measurement. The summer thermal comfort indicator is assessing the indoor thermal climate in summer on a critically hot and sunny day with PPM less than or equal to 15% for both residential and non-residential buildings. Daylight indicator requires proving good access to daylighting in the regularly occupied rooms through calculation or simulation. The Daylight Factor (DF) or the percentage of window glass area to floor parameter can be used. View area parameter can be used for non-residential buildings. The last indicator of the indoor environment is Legionella which requires the temperature of domestic hot water to be 50°C or more. The higher rating of Silver and Gold is given to continuous monitoring of the water temperature. Measuring and regulation (SGBC, 2015).

2.3 BIM for Simulation and Engineering Analysis

The frequency of BIM use as a faster way to only generate a 3D geometry and coordination is reported to be 60%. The availability of detailed building information and elements properties in an architectural BIM model could provide what is needed for building engineers to perform their duties with documentation, project management and engineering analysis. BIM tools are available to extend the application of an architectural model to other building disciplines. Structural analysis, Computational Fluid Dynamics (CFD), Life Cycle Analysis (LCA) thermal loads and energy analysis could all benefit from the geometrical representation and the existing attached data offered by the developed BIM model. The frequency of application in structural analysis is 27% and 25% for energy analysis (Kamel & Memari, 2019).

2.3.1 BIM for Building Energy Modelling

Several building energy and thermal comfort tools have been integrated into the BIM workflow

Figure 3. Some of the popular stand-alone building performance tools used by researchers and professionals are EnergyPlus, TRNSYS and IDA-ICE. EnergyPlus is open-source console-based software that reads input and writes output to a text file. To visualize the model and results graphically, a graphical user interface is needed. Several graphical interfaces are available for EnergyPlus such as OpenStudio Software Development Kit (SDK) and its applications (DOE and NREL, 2022). Another popular tool that visualizes and simplifies the simulation with EnergyPlus engine, is DesignBuilder (DesigBuilder Software Ltd., 2022). IDA Indoor Climate and Energy (IDA-ICE) is a simulation software developed by the Swedish company EQUA. IDA-ICE simulate the building performance according to the local Swedish standards, the local assessment system Miljöbyggnad and provides daylight calculation among other modules (EQUA Simulation AB, 2022) . These tools offer the capability of creating the graphical energy model within their own interface and are also able to import an existing architectural BIM model and map the data to be used for energy and thermal comfort analysis.

The popular BIM authoring tools have their own energy analysis plug-ins. Revit was integrated with EnergyPlus engine and DesignStudio SDK to provide energy analysis (Autodesk, 2019) in addition to Insight (Autodesk, 2022) ,the cloud-based tool that performs energy calculations on the BIM model and presents different design options (orientation, HVAC system type, walls construction components, window types etc.) to compare their impact on building's energy consumption and cost and help inform design decisions. Graphisoft has Ecodesigner STAR (Graphisoft, 2013) the Archicad plug-in for dynamic energy simulation developed in partnership with Strusoft and its BIM Energy analysis software (Strusoft AB, 2022).

The application of Building Energy Modelling within a BIM workflow has proven to be beneficial for many reasons such as ease of information handling, saving time and cost savings. Another benefit is avoiding human error when data transferred for analysis purposes. There is an added advantage of enhanced output for better documentation and project management. Some innovations used real-time data during operation to have an updated model (Kamel & Memari, 2019).

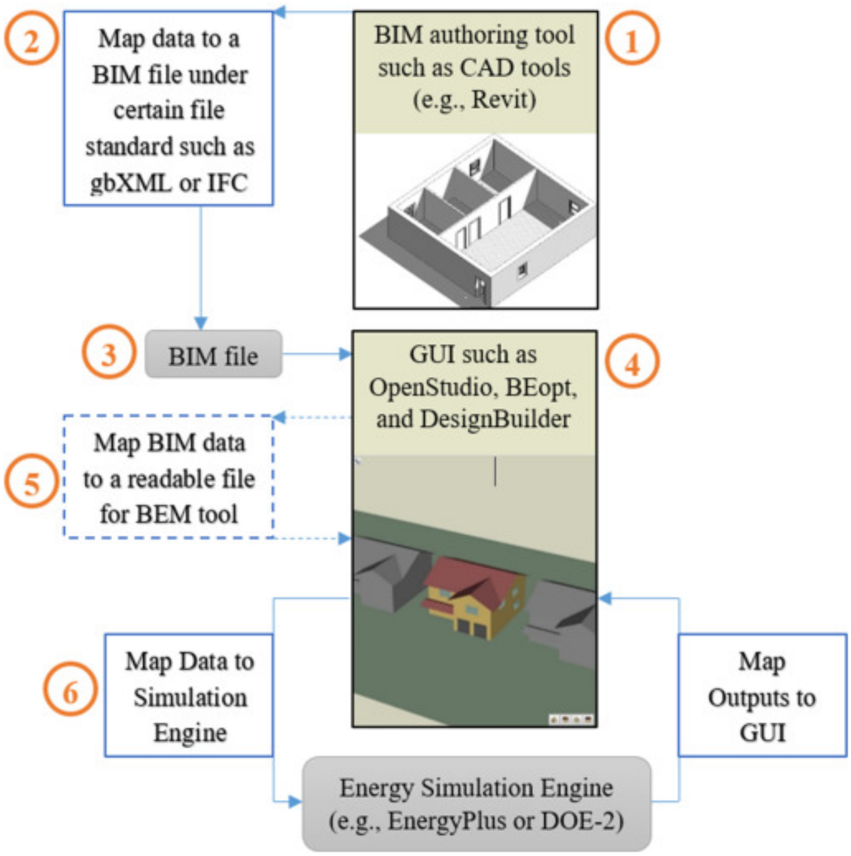

FIGURE 3: BEM WITHIN BIM WORKFLOW. SOURCE: (KAMEL & MEMARI, 2019)

Energy analysis tools should be versatile with integrated abilities to import and modify the input and visualize and export outputs. Sometimes it is required that the tool should be following standards such as ASHRAE 140-2017, UNI/TS 11300 and UNI EN ISO 52016-1 (Bonomolo, et al., 2021).

2.3.2 BIM for building environmental assessment

With the increasing popularity of green building practices to mitigate the acknowledged negative environmental impact of buildings and urban development, the demand to integrate sustainability strategies into planning, design and project delivery became an AEC industry focus. The BIM process has a great potential for integrating the delivery of assessment and certification obligations by creating templates to extract the essential reporting information from a model or to present the needed performance analysis. BIM integration of green building rating benefits was discussed in a case study using different platforms for LEED by (Ur Rahman, et al., 2022). Suggested methods for using BIM in LEED were developed in other publications. A rule-based LEED evaluation using BIM was proposed and its effect was evaluated with expert interviews to find out improvement characteristics (Kang, 2020). (Rahman, et al., 2021) Simulated and assessed the pre-certification of a residential building based on LEED categories and found a significant cost reduction. Daylighting simulation as an example for environmental assessment and sustainability found researchers' focus (Kota, et al., 2014), (Akin, et al., 2021), (Amoruso, et al., 2019). A solution to exchange BIM model data to perform acoustical analysis that includes programming was proposed by (Sušnik, et al., 2021). The application of BIM in Life Cycle Analysis (LCA) has been described as an optimization booster in the direction of sustainable development (Tushar, et al., 2021).

2.3.3 Data Exchange

While BIM authoring software has the capability to run the calculation and present results for some types of engineering analysis within its own GUI but sometimes for different reasons a specialized tools might be needed. In absence of a consensus standard, the interoperability issue continues to be a challenge in BIM implementation for the simulation of building performance. The suitable type of data and proper mapping for the extracted model data into the third-party tool is crucial for the success and accuracy of the results acquired by the tool.

The common file types that BIM authoring tools can produce for data exchange are IFC (Industry Foundation Class) and gbXML (Green Building eXtensible Markup Language). IFC file format is developed and maintained by BuildingSMART to deliver interoperability solution as a platform-independent open standard format. It was certified as an open international standard by ISO in 2013 as a standardized digital description of the built asset including infrastructure. IFC schema defines the physical asset components and their attributes such as material properties in a standard data model using a logical code (buildingSMART International, n.d.). The gbXML is now an organization backed by institutions and companies such as the U.S. Department of Energy (DOE), the American Society of Heating Refrigeration and Air conditioning Engineers (ASHRAE), National Renewable Energy Laboratory (NREL), Autodesk and Bentley. The schema was first submitted by Green Building Studio company to be included in an initiative led by Bentley called aecXML for architecture, engineering, and construction eXtensible Markup Language, then became an independent entity in 2009 (gbXML, n.d.).

3 Method

3.1 Case studies

Two Miljöbyggnad certified school buildings located in Gävle were used in this study. Photographs of the two buildings in Table 5. The two cases are new school buildings. Education buildings in general and especially primary and pre-schools has the focus of authorities in Sweden to be verified with the best environment for the children health and wellbeing.

3.1.1 Case 1: Almgården preschool extension building

The first case is the extension of Almgården preschool which was built in 2018 by Gävlefastigheter AB and certified with Miljöbyggnad 3.0 in 2019 with a SILVER final rating. The three stories building mainly consists of offices, living room, group room, dining room, kitchen, and workshop room on the first floor. The second floor consists of a workshop room, staff room, group room and restroom. The third floor only consists of a fan room which is included in the conditioned area A_{temp}. One electric elevator is installed. The building is connected to the district heating network with no cooling and is equipped with three air handling units with heat exchange (FTX).

3.1.2 Case 2: Strömsbro school new building

The second case is the new building of Strömsbro school. The two stories building was built in 2018 as a part of the school with a request from Gävlefastigheter AB. The building was certified with Miljöbyggnad 3.0 with a SILVER final rating. It mainly contains a large kitchen, dining room, music room, library, student healthcare room, office room, group room and an elevator. The building is connected to the district heating network with no cooling and is equipped with three air handling units with heat exchange (FTX).

TABLE 5: MILJÖBYGGNAD RATING FOR THE TWO CASES

Almgården school building

Område			Indikator	Aspekt	Område	Byggnad
Energi	1	Värmeeffektbehov	GULD	GULD	GULD	SILVER
	2	Solvärmelast	GULD			
	3	Energianvändning	GULD	GULD		
	4	Andel förnybar energi	GULD	GULD		
Innemiljö	5	Ljud	SILVER	SILVER	SILVER	
	6	Radon	BRONS	BRONS		
	7	Ventilation	SILVER			
	8	Fuktsäkerhet	SILVER	SILVER		
	9	Termiskt klimat vinter	SILVER	BRONS		
	10	Termiskt klimat sommar	BRONS			
	11	Dagsljus	BRONS	BRONS		
	12	Legionella	SILVER	SILVER		
Material	13	Loggbok med byggvaror	SILVER	SILVER	SILVER	
	14	Utfasning av farliga ämnen	SILVER	SILVER		
	15	Stommen och grundens klimatpåverkan	SILVER	SILVER		

Strömsbro school building

Område			Indikator	Aspekt	Område	Byggnad
Energi	1	Värmeeffektbehov	SILVER	SILVER	SILVER	SILVER
	2	Solvärmelast	GULD			
	3	Energianvändning	GULD	GULD		
	4	Andel förnybar energi	SILVER	SILVER		
Innemiljö	5	Ljud	SILVER	SILVER	SILVER	
	6	Radon	SILVER	SILVER		
	7	Ventilation	SILVER			
	8	Fuktsäkerhet	SILVER	SILVER		
	9	Termiskt klimat vinter	SILVER	BRONS		
	10	Termiskt klimat sommar	BRONS			
	11	Dagsljus	GULD	GULD		
	12	Legionella	SILVER	SILVER		
Material	13	Loggbok med byggvaror	SILVER	SILVER	SILVER	
	14	Utfasning av farliga ämnen	SILVER	SILVER		
	15	Stommen och grundens klimatpåverkan	BRONS	BRONS		

3.1.3 BIM models

A BIM model was generated for case 1: The new extension of Almgården School (Figure 4) and case 2: Strömsbro school (Figure 5). The two buildings are in the city of Gävle, Sweden. The BIM models were produced using Autodesk Revit 2021 by inserting the pdf version of the floor plans found in the documentation submitted for Miljöbyggnad indictors reporting by Ramboll. No CAD drawing files were available for the buildings. Drawing scales from the pdf files were used to model the floor plans. Information about airflow rates, set temperature, lighting efficiency, equipment loads, and occupancy was inserted into the model spaces. The fully detailed MEP distribution systems were not modelled. An analytical model was created in Revit and spaces were assigned to Air Handling Units (AHUs). Both studied buildings were Miljöbyggnad 3.0 certified with a final overall rating of SILVER.

The BIM models were used to evaluate the buildings' compliance with LEED v4 Energy and Atmosphere (EA) and Indoor Environment Quality (EQ) indicators requirements where a direct application is possible with the available tools.

Energy analysis was performed for the BIM model using Autodesk Insight, a cloud-based Revit tool. Whole building's energy analysis was also performed with IDA-ICE v4.8 by importing an IFC version of the BIM model exported from Revit. The IFC file was checked using with Solibri Anywhere the model checker for errors and compatibility of the analytical model with IDA-ICE IFC import function.

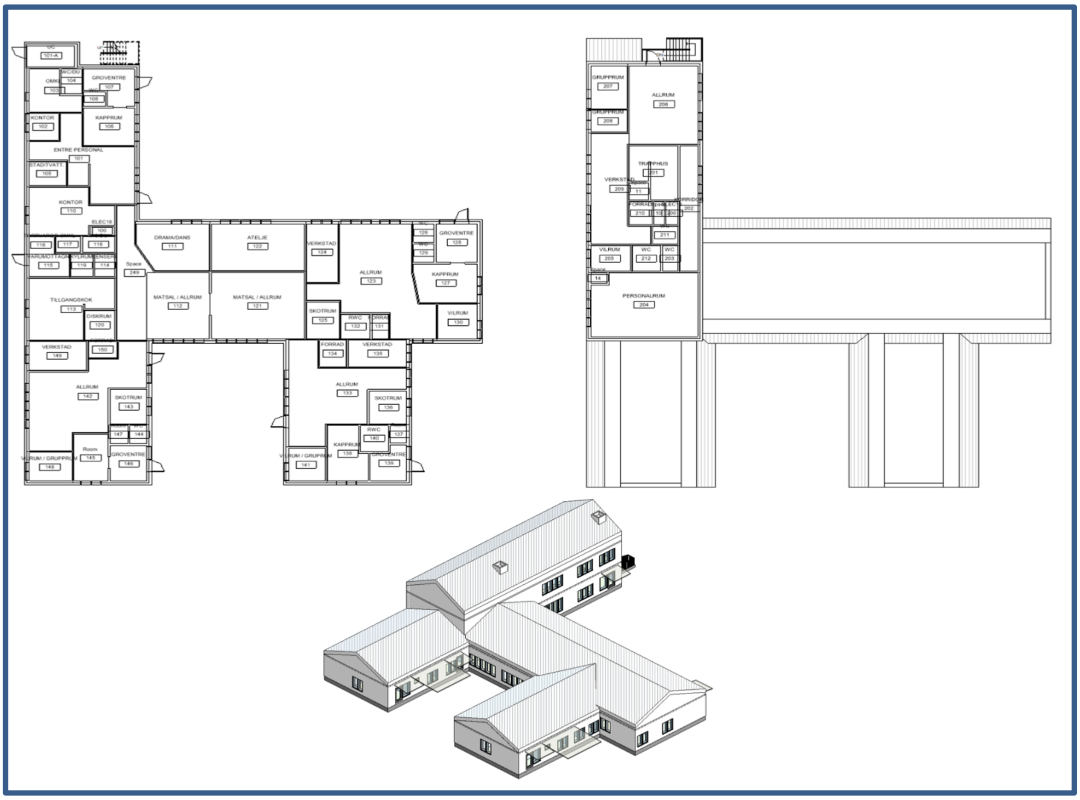

FIGURE 4: ALMGÅRDEN SCHOOL BUILDING BIM MODEL IN REVIT

FIGURE 5: STRÖMSBRO SCHOOL BUILDING BIM MODEL IN REVIT

Input information of the BIM model along with the analysis results and the available design information from Miljöbyggnad reports presented by the contractor was used for LEED requirements to examine how the buildings would score EA and EQ categories. Missing information needed for proper LEED reporting limited the evaluation of some credit compliance for this study. Energy costs used in the simulation were taken from Gävle Energi prices of district heating and electricity for 2022. District heating price is 0.4593 Kr/kWh and an annual fixed cost of 5 920 Kr/year. Electricity's price is 1.5 Kr/kWh and has an annual fixed cost of 11 408 Kr/year (Gävle Energi, 2022).

The BIM model information and analysis were used to check the credits' compliance for the cases where applicable. Revit Lighting plug-in was used for daylight analysis for LEED daylight credit. The method used to report this credit was presented by a member of Autodesk forums, Revit community section, as a solution to report the quality views credit through option 2 from a Revit model (Autodesk, 2017). A custom Space Schedule has been created to include and calculate the areas with a direct line of sight to the outdoor. The space separator tool is used to draw the direct line of sight and a "color fill legend" is created with a color scheme to mark the compliant area.

3.2 LEED EA and EQ

A summary of Energy and Atmosphere (EA) and Indoor Environmental Quality (EQ) credits requirements of LEED were presented by reviewing the current version of the LEED BD+C v4 user guide (USGBC, 2019) to evaluate the potential of achieving credit reward points.

3.2.1 LEED EA credits

EA Prerequisite 1: fundamental commissioning and verification

To meet the developed Owner's Project Requirement (OPR) and Basis of Design (BOD), a commissioning plan should be in place for Mechanical, Electrical and Plumbing (MEP) systems according to ASHRAE Guideline 0-2013 and ASHRAE Guideline 1.1-2007 for HVAC&R. Inclusion of exterior enclosures could be guided by ASTM E2947-16 standard. On-site renewable energy systems must be commissioned under this prerequisite. The plan must include: 1) A system narrative describing MEP systems and equipment, 2) The building's sequence of operations, 3) Detailed equipment runtime and building occupancy schedules, 4) Minimum outdoor air requirement, HVAC setpoints and lighting levels 5) Equipment preventive maintenance plan and 6) a program includes periodic commissioning, ongoing tasks, and continuous tasks.

An experienced Commissioning Authority (CxA) should be assigned after the design development stage to do the following: 1) Review the design, OPR and BOD, 2) Develop a commissioning plan, checklists, and test procedures. 3) Implement the plan and verify system test procedures and 4) Maintain a log for benefits and issues and document the findings and report to the owner and prepare a final report.

The CxA should have an experience of at least 2 years on at least 2 projects and could be an employee of the design or construction company who is not part of the project team.

EA Prerequisite 2: Minimum Energy Performance.

The whole-building energy simulation should be set up to calculate energy use by source and fuel including the heating and cooling loads, HVAC system. Infiltration, lighting and plug loads. In Miljöbyggnad the energy is calculated with the BBR method for the heated area A_{temp}. The calculated primary energy delivered to the building by source including heating, domestic hot water, comfort cooling and facility energy. The household and other functions' energy is not included.

The intent is to reduce environmental and economic harm by setting a minimum building's energy efficiency in the early project phase. This prerequisite requires the initiation of energy analysis in the early phase of design for the selection of informed efficiency strategies and to ensure updating and presenting the model with the changes that occurred throughout the project as an integrative design process which is required for the Integrative Process credit. Achieving this prerequisite demand compliance with ASHRAE 90.1-2010 standard or USGBC-approved standards for projects outside the U.S. with one of three options through these steps:

1- Identify climate zone using Annex 1 of the standard. International projects may also refer to Standard 169-2013 to determine climate zone according to historical data.
2- Address the mandatory requirements in sections 5.4 Building envelope, 6.4 HVAC, 7.4, Service water heating, 8.4 Power, 9.4 Lighting compliance and 10.4 coordination.
3- Identify the energy use benchmark. ASHRAE 209 5.4 and its Appendix B Benchmark Information or ENERGY STAR's Target Finder could be considered.
4- Select a credit compliance option from one of the following:
   - Option 1: Whole-building energy simulation with the provision of sections 5 -10 of the ASHRAE 90.1 standard through simulation by developing and comparing the Proposed Building Performance (PBP) model and Baseline Building Performance (BBP) model according to Appendix G Performance Rating Method of ASHRAE 90.1-2016.
   - Option 2: Section 11 Energy Cost Budget Method.
   - Option 3: Normative Appendix G Performance Method.
5- Develop a preliminary design model to estimate energy usage and evaluate it in different scenarios in the early design phase to guide design decision making.
6- Ongoing iteration of the early design phase model by updating the changes in the model to reflect the effect of changes in the savings relative to ASHRAE 90.1. This will contribute to achieving more points under related credit.

Option 2 and 3 are for eligible projects with simple upgrades to envelope, mechanical, lighting, appliances and/or process equipment. These options can be used by projects that are not pursuing Optimize Energy Performance credit to only comply with the prerequisite.

USGBC provide guidance for carbon dioxide equivalent emission reduction percentage and baseline for projects using Appendix G of the standard for the U.S., Canada and internationally. For international projects, the national grid mix coefficient shall be used to calculate energy source GHG emissions from International Energy Agency (IEA) CO_2 emissions from Fuel Combustion 2017 report. GHG emission factor for each energy source shall be determined with ISO Standard 52000-

1:2017. On-site renewable energy systems count towards energy-saving compliance and GHG emission offset. In Sweden, SGBC issued a report that suggested the way of handling District Energy Systems (DES) and the Nordic energy mix in LEED v2009 (SGBC, 2014).

USGBC advises that the baseline model is best to be prepared after all major decisions have been made and updated with the final project design to evaluate if the project will meet the targets.

EA Prerequisite 3: Building-Level Energy Metering

The prerequisite intent is to continuously identify additional energy saving opportunities by tracking the building-level energy consumption. The requirement is to install or use available building-level meter or aggregating energy submeters for all energy sources (electricity, natural gas, chilled/hot water, fuels etc.) and commit to sharing the meter data for 5 years starting from the certification date. Energy use must be reported at a minimum of one-month intervals. Projects can submit data to USGBC 's Arc platform to comply with the data sharing requirements.

EA Prerequisite 4: Fundamental Refrigerant Management

Intended to reduce Ozone layer depletion, the prerequisite requires not to use both Chlorofluorocarbon (CFC) and Hydro Chlorofluorocarbon (HCFC)-based refrigerants in new HVAC&R systems. If any existing equipment is reused, phase-out conversion should be done before project completion. Exemption from this requirement is for existing small units containing less than 225 grams of refrigerant or standard refrigerators, water coolers and any other equipment containing less than 225 grams.

EA Credit 1: Enhanced Commissioning

The credit intent is the continuous support of the design, construction, and operation to meet the OPR requirements and requires, in addition to the EA prerequisite requirements, implementation or having a contract in place for the Commissioning Process (CxP) activities listed in the following options:

Option 1: Enhanced System Commissioning

Path 1: Enhanced Commissioning

For 3 LEED points, the project team should complete the following activities for MEP and renewable energy systems according to ASHRAE Guidelines 0-2005 and 1.1-2007 for HVAC&R systems:

- Reviewing contractor submittals.
- Verifying, updating, and delivering the system manual and requirements in construction documents.

- Verifying the effectiveness and delivering operator and occupant training and its requirements.
- Verify seasonal testing.
- Review building operations after 10 months from completion.
- Develop an ongoing commissioning plan.

Path 2: Enhanced and monitoring-based commissioning

For 4 LEED points, in addition to achieving path 1, identification of measurement points to assess water and energy performances should be done with monitoring-based procedures developed and included in the commissioning plan to address roles and responsibilities, measurement requirements, frequency of monitoring, acceptable values and an action plan for repairs and correcting operational deficiencies.

Option 2: Building Enclosure Commissioning

This option is rewarded with 2 LEED points for fulfilling EA commissioning prerequisite requirements for the building thermal envelope in addition to mechanical and electrical systems and completing CxP activities for thermal envelope according to ASHRAE Guidelines 0-2005 and the National Institute of Building Science (NIBS) Guideline 3-2012 Exterior Enclosure Technical Requirements for the Commissioning Process. CxA should complete the same procedures mentioned for option 1 path 1 for building envelope commissioning.

EA Credit 2: Optimize Energy Performance

To reduce energy consumption's environmental and economic harms, the intent of this credit is to take energy performance beyond the prerequisite standard by requiring efficiency measures analysis, energy performance improvement and considering energy saving cost implications to account for the results in decision making.

The credit achievement has 2 options in LEED V4 BD+C: 1) Whole building simulation to show the percentage of improvement as per EA prerequisite Minimum Energy Performance method or 2) Prescriptive compliance to ASHRAE Advanced Energy Design Guide (AEDG) for projects using option 2 in the prerequisite.

Energy Use Intensity (EUI) is the metric that measure the yearly building energy performance expressed by the used energy per meter square of the area. The site EUI is the sum of energy use of all sources as reflected by the energy meters divided by the total area of the building. The source EUI converts all types of used energy to equivalent unit of raw fuel with a factor to account for production, transmission, and delivery of energy to the building (Figure 6) (Energy Star, 2022).

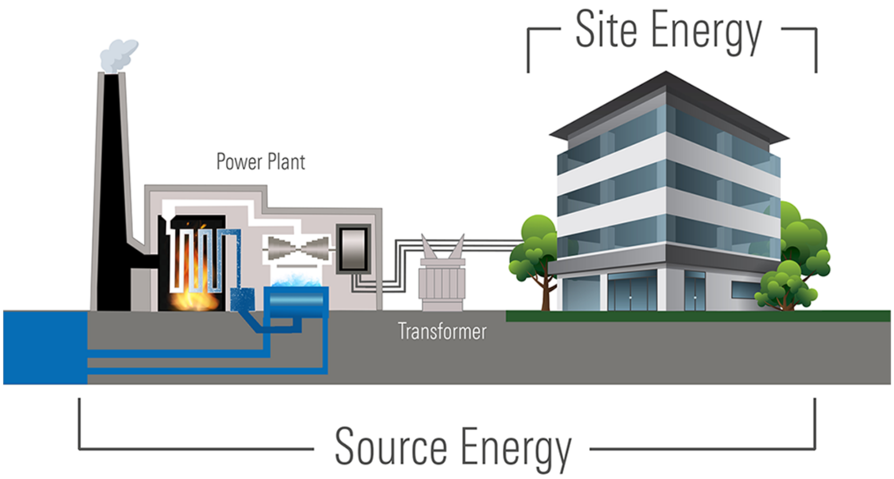

FIGURE 6: SOURCE ENERGY VS. SITE ENERGY SOURCE: ((ENERGY STAR, 2022)

In LEED rating system, a building energy model is required for EAp2 Minimum energy performance and EAc2 Energy performance optimization. For the pre request, it is recommended that a preliminary model is developed in the early design stage to investigate the energy effect and inform the decision making by modeling different scenarios. The model is only estimating the proposed design energy use and modelling the building late will only be a compliance tool.
The calculated energy in (kWh/m^2.year) must include the regulated energy use by Standard 90.1(envelop, HVAC, lighting, domestic hot water, motors and drives, elevators, refrigeration) and unregulated use (special purpose lighting, plug-in equipment, process equipment):

$$E = \frac{E_H + E_C + E_{DHW} + E_{M\&D} + E_L + E_{Elev.} + E_{Ref.} + E_{Plug} + E_{Proc.}}{A}$$

Where E_H is heating energy, E_C is cooling energy, E_{DHW} is domestic hot water energy, $E_{M\&D}$ is motors and drives energy, E_L is lighting energy, $E_{elev.}$ is elevator energy, $E_{Ref.}$ is refrigeration energy, E_{Plug} is energy used by plug-in equipment, $E_{proc.}$ is the process equipment energy.

For whole building simulation, the model should be completed and updated with the final construction details and create a baseline model as described Mandatory Provisions sections of ASHRAE 90.1 Normative Appendix G, Performance Rating Method. Projects achieve points with the percentage improvement from the baseline.

In Miljöbyggnad system, the primary energy use (EP_{pet}) is calculated in (kWh/A_{temp}.year) including space heating and cooling energy, domestic hot water, facility energy. Heating energy is t to be adjusted with the geographical adjustment factor (F_{geo}). Each energy use to be multiplied by energy carrier weighting factor. The calculated energy us is then compared to the use calculated according to BBR requirements. Gävle municipality has F_{geo}= 1.1.

$$EP_{pet} = \frac{\sum_{i=1}^{6}\left(\left(\frac{E_{sh,i}}{F_{geo}}\right) + E_{sc,i} + E_{DHW,i} + E_{fe,i}\right) WF_i}{A_{temp}}$$

Where: $E_{sh,i}$ is space heating energy from energy carrier i (kWh/a); $E_{sc,i}$ is space cooling energy from energy carrier i (kWh/a); $E_{DHW,i}$ is domestic hot water heating from energy carrier i; $E_{fe,i}$ is the facility energy from energy carrier i; W_{Fi} is the weight factor for energy carrier i.

For non-residential building, must not exceed 80 kWh/m^2 and average U value not to exceed 0.6 W/m^{2}K. BRONZE rating is given if building's energy use is equal or less than BRR requirements, SILVER for equal or less 70% of BBR requirements and GOLD for equal or less 60% of BBR requirements.

EA Credit 3: Advanced Energy Metering

With the intent of continuously looking for energy saving opportunities by tracking energy use in the building, this credit requires the installation of whole-building meters for all energy sources in addition to any end-use that is 10% or more of the annual energy consumption. The meters must be permanent and transmit data of both consumption and demand to a remote location with a record data interval of one hour or less. All meters must be capable of reporting hourly, daily, monthly, and annual consumption. The data collection system must be remotely accessible and able to store the data for at least 3 years. The advanced metering reward is one point.

EA Credit 4: Demand Response

The intent of this credit is to promote Demand Response (DR) technologies for more efficient generation and distribution systems, grid reliability and less GHG emissions. Projects can achieve points with one of two cases:

Case 1: Participation of a minimum of one year in an available qualified DR program for at least 10% of the peak electricity demand determined in EA Prerequisite Minimum Energy Performance. DR processes must be included in CxA work for at least one full test of the developed DR plan. In this case, the project achieves 2 points.

Case 2: The provision of an infrastructure that is ready for future DR or dynamic pricing programs, if no DR program is available. A plan must be developed for at least 10% shedding of the peak electricity demand determined in EA Prerequisite Minimum Energy Performance and include DR response in CxA for at least one full test of the plan. In this case, the projects achieve 1 point.

EA Credit 5: Renewable Energy Production

To encourage the increase of renewable energy supply in projects to reduce fossil fuel energy and GHG emissions, this credit requires the installation of on-site renewable energy systems or procurement of all or portion of annual energy use from offsite renewable sources. The percentage of building's renewable energy to be calculated with the equation:

$$\%\ \text{Renewable energy} = \frac{\text{Equivalent cost of produced renewable energy}}{\text{Total annual energy cost}}$$

Where total annual energy cost calculated in EA prerequisite Minimum Energy Performance for option 1. If the project does not comply with option 1 of the prerequisite, then the estimate of energy use and cost could be taken from the U.S. Department of Energy's Commercial Building Energy Consumption Survey (CBECS) database. For new construction projects, points for renewable energy are given according to percentage with one point for 1% and a maximum of 3 points for 10% of the annual use.

EA Credit 6: Enhanced Refrigerant Management

To reduce Ozone Depletion Potential (ODP), Global Warming Potential (GWP) and contribution to climate change, this credit require no use of refrigerant or the use of only refrigerant with an ODP of zero and GWP of less than 50 as a compliance option with one point. Another option, for one point, is to choose refrigerant for HVAC&R equipment that comply with the following formula for Lifecycle Ozone Depletion (LCODP) and Lifecycle Global Warming Potential (LCGWP):

$$\text{LCGWP} + \text{LCODP x } 10^5 \leq 13$$

Where: LCODP (Kg CFC 11/(kW/year)) = [ODP_r x (L_r x Life + M_r) x Rc] / Life

LCGWP (Kg CFC 11/(kW/year)) = [GWP_r x (L_r x Life + M_r) x Rc] / Life

GWP_r is refrigerant GWP (0 to 12000 kg Co2/kg_r), ODP_r is Refrigerant ODP (0 to 0.2 Kg CFC 11 kg_r), Lr is refrigerant leakage rate (2.0%), Mr is end-of-life refrigerant loss (10%), Rc is refrigerant charge (0.065 to 0.65 Kg of refrigerant per kW of AHRI or Eurovent certified cooling capacity) and Life is the equipment life (10 years; default for equipment type, unless otherwise demonstrated).

If multiple types of equipment are used the formula is as follows:

$$\frac{[\,\Sigma\,(\,LCGWP\ +\ LCODP\ x\ 10^5\ )\ x\ Q_{unit}\ ]}{Q_{total}} \leq 13$$

Where Q_{unit} is Eurovent certified capacity of individual HVAC or Refrigeration unit (kW) and Q_{total} is the total Eurovent certified capacity of all HVAC or refrigeration (kW).

3.2.2 LEED EQ credits

EQ Prerequisite 1: Minimum indoor air quality performance

With an intention to set a minimum standard for Indoor Air Quality (IAQ), This prerequisite requires that the outdoor air intake for ventilated spaces to or exceed the minimum acceptable requirements of ASHRAE Standard 62.1-2010. A local equivalent standard can be used if it is more stringent. Projects outside the U.S. can use European Standardization Organization (CEN) Standards EN 15251-2007 and EN 13799-2007.

Table 6 shows the outdoor minimum and additional requirements for some spaces both ASHRAE 55 and EN 15251 standards. Monitoring of outdoor air intake is required for mechanically and naturally ventilated spaces.

Standard EN 15251 defines category I with high level of expectations for spaces occupied by occupants with special requirements such as elderly, disabled, or young children. The requirement for occupied spaces in a school must be 5% to 6% PPD and PMV between -0.2 and 0.2.

TABLE 6: OUTDOOR AIR REQUIREMENT FOR GENERAL COMFORT IN SPACES IN ASHRAE 62 AND EN 15251

EN 15251			ASHRAE 55	
Category	**PPD**	**PMV**	**PPD**	**PMV**
I	<6%	-0.2<PMV<0.2		
II	<10%	-0.5<PMV<0.5	<10%	-0.5<PMV<0.5
III	<15%	-0.7<PMV<0.7		

EQ Prerequisite 2: Environmental tobacco smoke control

This is intended to prevent building occupants, ventilation systems and indoor surfaces from tobacco smoke. The requirement is that smoking is prohibited inside the building and within at least 7.5 meters from all entries, operable windows, and outdoor air intakes. Signage must clearly indicate the policy and be located within 3 meters of the building's entries. Another option is the compartmentalization of smoking areas. For school projects, smoking is prohibited on site.

EQ Prerequisite 3: Minimum acoustic performance

This is a special prerequisite for schools, intended to facilitate the learning environment in classrooms. Exterior noise should be treated and minimized for high noise sites. HVAC background noise should be controlled to be less than 40 dBA by following chapter 48 of ASHRAE HVAC Application Handbook 2011; ANSI standard S12, part 1, Annex A.1; AHRI Standard 885-2008. For projects outside the U.S., a local equivalent can be used. Sound absorptive finishes with at least 0.7 NRC should be equal to or exceed the room's ceiling area of the classrooms. Another option is to comply with reverberation time calculations in the ANSI standard S12-2010. The core learning spaces which are less than 566 meters should meet the NRC-CNRC Construction Technology Update No. 51, Acoustical Design of Rooms for speech (2002) or equivalent standards for projects outside the U.S.

EQ Credit 1: Enhanced indoor air quality strategies

The credit is promoting the comfort and well-being of the occupants with enhanced strategies for mechanically ventilated spaces, naturally ventilated spaces, and mixed-mode systems. Only mechanically ventilated spaces requirements are discussed in this study as it is the most used in building projects as well as in the studied cases. For one point, option 1 can be used for mechanically ventilated with compliance be made for entryway systems, interior cross-contamination, and filtration. A 3 meters long entryway system must be installed with a weekly maintenance commitment. Spaces where chemicals or hazardous gases are present must be under negative pressure with an exhaust of 2.54 l/s to prevent cross-contamination. An additional point is available for mechanically ventilated spaces by selecting one of option 2 requirements which include: Prevention of exterior contamination using modelling and analysis methods such as Computational Fluid Dynamics (CFD) to demonstrate that the intake of outdoor air pollutants regulated by the National Ambient Air Quality Standards (NAAQS) are less than the allowable average annual concentration. Local standards can be used for projects outside the U.S. if they are more stringent. The second option is an increase in occupied spaces ventilation rate determined in the minimum IAQ prerequisite by more than 30%. The third option is to install CO_2 monitors in all densely occupied spaces. The fourth option is additional evaluation, monitoring, and handling of potential pollutants other than CO_2.

EQ Credit 2: Low-emitting materials

The intent of this credit is to protect occupants' health, productivity, and indoor air from harmful emissions from chemicals in building materials contents. It includes the evaluation of Volatile Organic Compound (VOC) in air and material contents, in addition to the testing methods to determine their emissions. With the water-proofing system considered as a separation line between the building's interior and exterior, the building's interiors and exteriors were organized into seven categories with different compliance thresholds. The waterproofing system itself is included in the exterior. School projects have additional exterior applied product requirements. Points can be achieved by the number of compliant categories. School projects can score 1, 2 or 3 points for complying with 3,5 or 6 categories respectively. If the furniture is included in a school project scope of work, the potential score would be 1, 2 or 3 points for 4, 6 or 7 compliant categories.

Another option is available with the budget calculation method to be used if a category product does not meet the necessary criteria. The budget calculation option rewards the total compliance percentage between 50 and 70% with one point, between 70 and 90% with two points and three points for 90% or more. Total project compliance percentage to be calculated by dividing the summation of percentage compliance for walls, ceilings, flooring, and insulation by 4 or by 5 if the furniture is added. The percentage of system compliance is calculated as the sum of the compliant layers' surface areas divided by the total surface area of all layers.

For emission and material content requirements to be demonstrated, the following is required: 1) Products with inherently non-VOC-emitting sources such as ceramic, concrete, glass and clay bricks are considered fully compliant without testing. 2) General emissions evaluation for building products must be tested according to the California Department of Public Health (CDPH) method v1.1-2010 with the applicable exposure scenario stated by the manufacturer. For projects outside the U.S., LEED v4 guide mentioned some international standards, such as the German AgBB scheme and ISO 1600, as options for testing, if the product's testing details method specified in the standard. 3) For the health of installers, on-site wet-applied products must be tested for excessive levels of VOC. Paints must meet the limits of the California Air Resources Board (CARB) 2007, Architectural Coatings Suggested Measures (CSM) or Rule 1113 of the South Coast Air Quality Management District (SCAQMD) 2011. Wet-applied adhesives and sealants' chemical contents must meet the requirement of Rule 1168 of SCAQMD 2005. Projects outside the U.S. can choose to comply with national VOC control regulations such as the European Decopaint Directive (2004/42/EC). 4) Composite wood must not have formaldehyde resins or must meet CARB's low formaldehyde emissions. 5) Furniture must be tested according to ANSI/BIFMA Standard Method M7.1-2011.

For school projects, batt insulation products with no formaldehyde are required, in addition to exterior applied products' testing to meet the limits of CARB and Rule 1168 of SCAQMD.

EQ Credit 3: Construction indoor air quality management plan

To minimize the impact of construction air quality problems, this credit requires the development and implementation of a preoccupancy IAQ management plan rewarded with one point. The plan must address the following: 1) Meet and exceed the recommended control measures of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ guideline for occupied building under construction 2nd edition, 2007, ANSI/SMACNA 008-2008, chapter 3. 2) Moisture damage protection for materials stored on site. 3) Air handling equipment filtration to be with a Minimum Efficiency Reporting Value (MERV) of 8, if operated during construction the final design filters must be installed immediately before occupancy.

4) Prohibit smoking inside the building and within 7.5 meters of the entrance during construction.

EQ Credit 4: Indoor air quality assessment

This credit is meant to ensure better IAQ after construction and during occupancy. One of two options is required to fulfil the requirements. Option 1, rewarded with 1 point, is flush-out. Air flushing can be done before occupancy by supplying 4.3 million l/m^2 of gross floor area and maintaining the temperature between 15°C and 27°C with a maximum relative humidity of 60%. Another compliance path is allowed if the building is occupied before the flush-out is complete by supplying at least 1 million l/m^2 of the gross area maintaining temperature and relative humidity as the same limits of the first path. Option 2, rewarded with 2 points, is to perform an indoor air testing before occupancy for contaminant concentration levels using protocols that are consistent with ASTM Standard methods, EPA compendium methods or ISO methods. Contaminants to be tested include Particulates, ozone, CO, Total Volatile Organic Compound (TVOCs), Formaldehyde and target volatile compounds from the California Department of Health (CDPH) standard method v1.1.

EQ Credit 5: Thermal comfort

This credit requires meeting both thermal comfort design and control for increased occupant's productivity and promote their wellbeing. Two options are available to fulfil the thermal comfort requirements, each one would achieve the one point that rewards this credit. Option 1 is by designing an HVAC system to meet the requirements of ASHRAE Standard 55-2010, Thermal Comfort Conditions for Human Occupancy. Option 2 requires the HVAC design to meet ISO 7730:2005, Ergonomics of the Thermal Environment using Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices and local thermal criteria and CEN Standard CEN 15251:2007 Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings.

For schools and new construction projects, thermal comfort controls must be provided to control at least one of the following: air temperature, radiant temperature, airspeed, and humidity. Individual thermal comfort controls for at least 50% of individual occupant spaces and group controls for all shared multi-occupant spaces. The recommended values of PPD and PMV are shown in Table 6. An operative temperature ranging between 20°C and 24°C in winter and between 23°C to 26°C in summer is required for a sedentary occupant based on the PMV-PPD index. EN 15251 uses the mean weekly outside temperature while ASHRAE 55 uses monthly average.

EQ Credit 6: Interior Lighting

High quality lighting is promoted with this credit through two options with one point each available for projects to score two points maximum. Option 1, Lighting quality, requires providing three-level control (on, off, midlevel) for 90% or more of individual occupant spaces. All multi-occupant spaces must have the same control located within the space. Projection and presentation lighting must be separately controlled. Option2 is lighting quality through one of three strategies: 1) A luminance of less than 2 500 cd/m^2 between 45 and 90 degrees from the straight line directly pointing down from the center of the luminaire (nadir), must be used for lighting fixtures in all regularly occupied spaces. 2) Light sources with Color Rendering Index (CRI) of at least 80, must be used for the entire project with an exception for special use lighting. 3) Light sources with a rated life of not less than 24 000 hours for at least 75% of the total connected lighting load. 4) Use of overhead direct lighting for 25% or less for regularly occupied spaces. 5) Area-weighted average surface reflectance of 85% for ceilings, 60% for walls and 25% for floors must be met or exceeded 90% of regularly occupied spaces. 6) Area-weighted average surface reflectance of 45% of work surfaces and 50% for movable partitions must be met or exceeded for these furniture surfaces if the furniture is included in the scope of work. 7) 75% of regularly occupied spaces must have no more than 1:10 as the ratio between average wall surface illuminance and average work plane or demonstration of average surface reflectance for 60% of the walls. 8) 75% of regularly occupied spaces must have no more than 1:10 as the ratio between average ceiling surface illuminance and average work plane or demonstration of average surface reflectance for 60% of the ceilings.

EQ Credit 7: Daylight

Introducing daylight to the space to reduce electrical lighting, reinforce circadian rhythms and connect occupants to the outdoors is promoted to achieve a maximum of three points through three options. Option 1: Simulation of spatial Daylight $\text{Autonomy}_{300/50\%}$ ($\text{sDA}_{300/50\%}$) to demonstrate that 55% of the regularly occupied floor area was achieved for 2 points, or 75% or more for 3 points. Annual Sunlight $\text{Exposure}_{1000,250}$ ($\text{ASE}_{1000,250}$) of 10% to be demonstrated. sDA and ASE should be calculated at 760 millimeters height work plane with 600 millimeters square grids across the space using hourly step analysis and typical year metrological data.

Option 2: Illuminance calculation by computer simulation to model illuminance level of regularly occupied spaces to be 300 lux and 3,000 lux for 9 a.m. and 3 p.m. on a clear sky day at the equinox using typical metrological year data. The building would get one point if 75% of the regularly occupied areas meet the requirement and 2 points for 90% of the area. Permanent interior obstruction to be included. Shades and blinds are to be excluded from the model.

Option 3: Measurement of illuminance level between 300 lux and 3,000 lux at appropriate work plane height between 9 a.m. and 3 p.m. A second measurement should be taken in the timing advised by LEED v4 guide. Two points would be scored if 75% of the regularly occupied floor area achieved the level and 3 points for 90% of the area.

EQ Credit 8: Quality views

For a maximum of 2 points, this credit intends to connect the occupants to the surrounding natural outdoor environment by providing clear direct sight of the outdoors via glazing for 75% of the regularly occupied floor area. 30% of the required area may be counted for views into interior atria. Two of the following kinds of view must be available for 75% of floor area:

1) Multiple lines of sight at least 90° apart.
2) At least two of the following to be included in the views: a) plants (flora), animals (fauna) or sky; b) movement; and c) objects that are 7.5 meters from the glazing.
3) Unobstructed views within the distance of three times the head of glazing.
4) Views with a factor of three as defined in "Windows and Offices: A Study of Office Work Performance and the Indoor Environment" (H.M.G, 2012).

EQ Credit: Acoustic performance

One LEED point is available to promote the effective acoustic design for better communication and enhance productivity in classrooms and workspaces. For school projects, the requirements are reducing HVAC background noise and sound transmission. The background noise level from the HVAC system should be less than or equal to 35 dBA. This would be achieved by following best practices and methods in ANSI Standard S12.60-2010, Part 1, Annex A.1; the 2011 HVAC Applications ASHRAE Handbook, chapter 48, Sound and Vibration Control; AHRI Standard 885-2008, or local applicable equivalent. The design of core learning spaces should meet Sound Transmission Class (STC) requirements of ANSI S12.60-2010, Part 1 or an equivalent local standard. If outdoor and indoor noise levels are not verified as a low-level rating, the exterior windows should have an STC of 35.

4 Results

The BIM model was used to evaluate the potential LEED score for the two cases in the EA and EQ categories where it has direct application. In the EA the BIM model was used in for the energy prerequisite and credit which are assessing performance. The other credits are assessing either a feature or a procedure. In the EQ category, the BIM model helped to evaluate the compliance with the IAQ prerequisite and credit, the daylight and quality views credits. The BIM feature of creating customized schedules can provide the necessary data from the design to the certification reports. The interior lighting credit is an example of such application, but unfortunately the lighting details were not available for this study. The results of the two cases potential compliance with LEED AE and EQ are detailed in the following sections with a comparison to the achieved Miljöbyggnad rating in the similar indicators.

4.1 Case studies LEED EA and EQ Credits

The design of two buildings, Almgården school (as case 1) and Strömsbro school (as case 2), were evaluated with the specified requirements for school projects of LEED v4 BD+C EA and EQ credits to realize the potential score. The BIM models and the analysis were used to fulfil credits' requirements where applicable. Most LEED credits require reporting of activities throughout the design and construction process. Some information about the buildings studied was not available to evaluate how the project could achieve certain requirements. The two buildings are existing and their design information and Miljöbyggnad reporting were used for the purpose of this study.

4.1.1 LEED EA credits in the two cases:

Energy analysis and optimization have the biggest share of points in this category by 16 available points and a prerequisite requires detailed reporting of energy consumption and sources. 25 and 13 points are the potential scores for cases 1 and 2 respectively. The detailed score is shown in

Table 7 and Table 8.

TABLE 7: LEED EA POTENTIAL SCORE OF CASE 1, ALMGÅRDEN SCHOOL BUILDING

	Energy and Atmosphere	Type of Aspect assessed	Points	BIM tool
EAp1	Fundamental Commissioning and Verification	Procedure	Required	
EAp2	Minimum Energy Performance	Performance	Required	Revit/Insight
EAp3	Building-Level Energy Metering	Feature	Required	
EAp4	Fundamental Refrigerant Management	Procedure	Required	
EAc1	Enhanced Commissioning	Procedure	4 / 6	
EAc2	Optimize Energy Performance	Performance	6 / 16	Revit/Insight/ IDA-ICE
EAc3	Advanced Energy Metering	Feature	1 / 1	
EAc4	Demand Response	Procedure	0 / 2	
EAc5	Renewable Energy Production	Performance	2 / 3	
EAc6	Enhanced Refrigerant Management	Procedure	0 / 1	
EAc7	Green Power and Carbon Offsets	Procedure	2 / 2	
	Potential points:		**15 / 31**	

TABLE 8: LEED EA POTENTIAL SCORE OF CASE 2, STRÖMSBRO SCHOOL BUILDING

	Energy and Atmosphere	Type of Aspect assessed	Points	BIM tool
EAp1	Fundamental Commissioning and Verification	Procedure	Required	
EAp2	Minimum Energy Performance	Performance	Required	Revit/Insight
EAp3	Building-Level Energy Metering	Feature	Required	
EAp4	Fundamental Refrigerant Management	Procedure	Required	
EAc1	Enhanced Commissioning	Procedure	4 / 6	

EAc2	Optimize Energy Performance	Performance	6 / 16	Revit/Insight / IDA-ICE
EAc3	Advanced Energy Metering	Feature	1 / 1	
EAc4	Demand Response	Procedure	0 / 2	
EAc5	Renewable Energy Production	Performance	0 / 3	
EAc6	Enhanced Refrigerant Management	Procedure	0 / 1	
EAc7	Green Power and Carbon Offsets	Procedure	2 / 2	
	Potential points:		**13 / 31**	

Below are the details about how the potential score is achieved following LEED guidelines summarized on the method section with available information about the two cases.

EAp1: Fundamental commissioning and verification

No information for both cases about the commissioning plan, execution and the CxA. If the project was pursuing LEED certification the process would have been executed and documented according to BOD, OPR and certification requirements.

EAp2: Minimum Energy Performance

The developed BIM models have been used for whole-building energy analysis with Autodesk Insight cloud tool which enabled the visualization of the impacts of design options and efficiency strategies on the building. It is required under this prerequisite to report the details of the building's energy use including types of energy source, general HVAC information and modelling, water heating, process loads, lighting, windows and shading, opaque assemblies, operation schedules and energy cost savings. The preliminary energy estimation and the schedules of the BIM model provided the necessary information to evaluate and compliance documentation. The tool provides a comparison against Architecture 2030 and ASHRAE 90.1 models as benchmarks. The latter is required for this prerequisite. Table 9 shows the analysis results for the proposed design. The analysis and comparison details for both cases are shown in Appendix A.

The target was set to be the reduction of Energy Use Intensity (EUI) from ASHRAE 90.1 model to achieve LEED points in Optimizing energy performance credit EAc2. The prerequisite requires the proposed design to demonstrate 5% improvement from the baseline model.

TABLE 9: ENERGY USE INTENSITY AND COST OF THE TWO CASES MODELS IN INSIGHT COMPARED TO ASHRAE 90.1 MODELS

		Design	ASHRAE 90.1	Improvement %
Case 1: Almgården	Cost ($/m^2.year)	8.2	12.03	32%
	EUI (kWh/m^2.year)	116	184	37%
Case 2: Strömsbro	Cost ($/m^2.year)	4.87	5.07	4%
	EUI (kWh/m^2.year)	68.6	73.4	7%

EAp3: Building level energy metering

The buildings were equipped with utility meters to measure and track energy consumption. The meters data can be registered and reported for compliance.

EAp4: Fundamental refrigerant management

Each of the two buildings includes a refrigeration room but no information was available for this study about the equipment and refrigerant used.

EAc1: Enhanced commissioning

With planning and executing MEP systems commissioning plan for 3 points and developing a monitoring-based procedure to assess the buildings' operation performance for 1 point, The Two cases can achieve at least 4 points.

EAc2: Optimize energy performance

Both buildings can use option 1: whole-building energy performance simulation. A simulation was performed using the BIM model with IDA-ICE and the Insight simulation used for EAp2 was revised as well. An IFC file of the building was exported using Revit 2021 and imported into IDA-ICE 4.8.

Simulation results for case 1 Almgården school, in Table 10, showed delivered energy of 100.2 kWh/m^2 for the proposed design which resulted in a 32% improvement from baseline (147 kWh/m^2). The calculated cost improvement of 16% can achieve 6 points out of 16 points available for schools.
Results for case 2 Strömsbro school,

Table 11, showed delivered energy of 86.95 kWh/m^2 which resulted in a 40% improvement from baseline (143.8 kWh/m^2). The calculated cost improvement of 17% can achieve 6 points out of 16 points available for the school's rating system.

TABLE 10: SUMMARY OF THE DELIVERED ENERGY IN CASE 1 AS SIMULATED BY IDA-ICE

ASHRAE 90.1 Model				
Meter	**Total, kWh**	**kWh/m^2**	**Peak demand, kW**	**Cost (SEK)**
HVAC aux	7 179.1	6.781	4.714	22 177
Elevator	2 092.5	1.976	0.8874	14 546
District heating	139 014	131.3	59.88	74 773
Lighting, tenant	8 289.7	7.83	4.292	23 842
Equipment, tenant	4 274.9	4.038	2.213	17 819.2
PV production	-5 202.1	-4.914	-1.813	3 604.7

Total	**155 648.1**	**147**	**70.17**	**156 761.9**
Proposed Design Model				
Meter	**Total, kWh**	**kWh/m²**	**Peak demand, kW**	**Cost (SEK)**
HVAC aux	7 281.8	6.878	5.039	22 331
Elevator	2 097.6	1.981	0.8874	14 555
District heating	89 372	84.42	44.39	50 187
Lighting, tenant	8 293.9	7.834	4.292	23 849
Equipment, tenant	4 277.1	4.04	2.213	17 823.4
PV production	-5 202.4	-4.914	-1.813	3 604.5
Total	**106 120**	**100.2**	**55.01**	**132 349.9**

TABLE 11: SUMMARY OF THE DELIVERED ENERGY IN CASE 2 AS SIMULATED BY IDA-ICE

ASHRAE 90.1 model				
Meter	**Total, kWh**	**kWh/m²**	**Peak demand, kW**	**Cost (SEK)**
HVAC aux	8552	8.529	5.669	24236
Elevator	2601.8	2.595	0.297	15307
Facade Lighting	740	0.738	0.08447	12517.3
District heating	110233	109.9	50.84	60517
Lighting, tenant	11062.8	11.03	4.769	28002.9
Equipment, tenant	10999.9	10.97	4.741	27907.9
Total	**144189.5**	**143.8**	**66.4**	**168488.1**

Proposed design model				
Meter	**Total, kWh**	**kWh/m²**	**Peak demand, kW**	**Cost (SEK)**
HVAC aux	8552.7	8.529	5.669	24236
Elevator	2601.8	2.595	0.297	15307
Facade Lighting	740	0.738	0.08447	12517.3
District cooling	0.000436	4.4E-07	5.6E-07	
District heating	53235	53.09	34.24	32287.9
Lighting, tenant	11061.8	11.03	4.769	28000.9
Equipment, tenant	10998.7	10.97	4.741	27903.9
Total	**87190**	**86.95**	**49.8**	**140253**

EAc3: Advanced energy metering

Meters are installed in the building for whole building energy metering and for the individual energy use, but there is no information about whether a data collection system or a Building Management System (BMS) exists in the two buildings. The one point allocated for this credit was scored as not achieved.

EAc4: Demand response

No information about the project's participation or the availability of demand response programs. No documentation for planning the systems to be ready for demand response programs. No point was claimed from the two available points.

EAc5: Renewable energy production

Case 1 Almgården school includes a rooftop PV system designed to produce 5 700 kWh/year. The equivalent cost of the energy produced by the system is determined in IDA-ICE calculation to be 3 605 SEK/year while the total building energy cost was 132 350 SEK/year which resulted in 3% on-site produced renewable energy. This percentage qualifies the building for 2 points out of the 3 available points.

Information about case 2 Strömsbro school building produced renewable energy was not available for this study. A PV system was planned but was not included in the reporting documents for Miljöbyggnad.

EAc6: Enhanced refrigerant management

No information about the refrigerant used for the refrigeration rooms within the two buildings. The credit is marked as not achieved.

EAc7: Green power and carbon offset

The two cases can achieve 2 points in this credit by providing the documents for 100% renewable energy supplied to the building. Proving documents from the energy suppliers were used to report the renewable energy indicator for Miljöbyggnad certification.

4.1.2 LEED EQ credits in the two cases:

The BIM model was applied to a prerequisite and four credits of the indoor environmental quality category. The two buildings have the same potential to achieve 5 out the 16 available points (Table 12).

TABLE 12: POTENTIAL LEED EQ SCORE IN THE TWO CASES (BOTH CASES HAVE THE SAME SCORE)

	Indoor Environmental Quality	Type of Aspect assessed	Points	BIM tool
EQp1	Minimum Indoor Air Quality Performance	Performance	Required	IDA-ICE
EQp2	Environmental Tobacco Smoke Control	Procedure	Required	
EQp3	Minimum Acoustic Performance		Required	
EQc1	Enhanced Indoor Air Quality Strategies	Feature/Procedure	2 / 2	

EQc2	Low-Emitting Materials	Performance	0	/	3	
EQc3	Construction Indoor Air Quality Management Plan	Procedure	0	/	1	
EQc4	Indoor Air Quality Assessment	Performance	0	/	2	
EQc5	Thermal Comfort	Performance	1	/	1	IDA-ICE
EQc6	Interior Lighting	Feature/Procedure	0	/	2	Revit
EQc7	Daylight	Feature	0	/	3	Revit
EQc8	Quality Views	Feature	1	/	1	Revit
EQc9	Acoustic Performance	Feature/Performance	1	/	1	
	Potential points:		**5**	**/**	**16**	

Below are the details about how the potential score is achieved following LEED guidelines summarized on the method section with available information about the two cases.

EQp1: Minimum indoor air quality performance

The BIM models with the attached rooms and space information can facilitate the compliance reporting of this credit. A schedule can be created in Revit to include all mechanical ventilated spaces with their area, space type, occupancy, and airflow. The same information is available from the analysis program. IDA-ICE report room by room compliance with classification categories of CEN EN 15251. Maximum CO_2 and Predicted Percentage of Dissatisfied (PPD) can be reported from IDA-ICE results to comply with EN 13779-2007. IDA-ICE results are shown in Appendix B.

EQp2: Environmental tobacco smoke control

Smoking is prohibited in school buildings, so the two cases will achieve this prerequisite as per LEED guidance for school projects.

EQp3: Minimum acoustic performance

Acoustic design reports have been attached with the Miljöbyggnad report for the sound indicator including the design evaluation according to BBR, Standard SS 25268:2007 and the Swedish Public Health Agency's general recommendation for indoor noise (FoHMFS 2014:13). Compliance with local standards is allowed for LEED compliance, thus the reported values for HVAC background noise, exterior noise, classrooms, and core learning spaces satisfy requirements. The reports' conclusions for both cases are shown in Table 13.

TABLE 13: SOUND CLASSES ACHIEVED IN LOCAL STANDARDS FOR THE TWO CASES AS PER MILJÖBYGGNAD REPORTS

Parameter	SS 25268:2007 requirement achieved	
	Case 1, Almgården	Case 2, Strömsbro
Airborne sound insulation	Sound class C	Sound class C
Step sound	Sound class C	Sound Class B
Installation noise	Sound class B, and FoHMFS 2014: 13 in rooms where children stay permanently	Sound class C
Traffic noise	Sound class B	Sound class B
Room acoustics	Sound class C, however, so-called "increased absorption" in the event of any deviations for airborne sound insulation within the department	Recommendations for construction materials was detailed for the regularly occupied spaces in the report

EQc1: Enhanced indoor air quality

The two buildings would score one point by including option 1 three strategies and another point if increased ventilation in occupied spaces is selected from option 2 for a total of 2 points. Appendix B is showing the simulation results for ventilation rate.

EQc2: Low emitting materials

The detailed information about interior and exterior emitting materials used in the two cases such as paints, adhesives and thermal insulation was not available for this study, so this credit was marked as not achieved. The BIM model, if populated with materials specifications, would be helpful in providing quantities by areas and volumes to report this credit's requirements.

EQ Credit 3: Construction indoor air quality management plan

This credit requires developing and following an IAQ plan during the construction phase, but no such information was available for the study.

EQ Credit 4: Indoor air quality assessment

Complying with the requirements of this credit through flush out or air testing needed to be done immediately before occupancy and information about the procedure in the two buildings to evaluate the compliance.

EQ Credit 5: Thermal comfort

Simulation results for both buildings can show compliance with local thermal comfort criteria. PMV and PPD indices were calculated in IDA-ICE which can also present space by space thermal comfort graphs according to EN 15251. The point for this credit can be claimed for both cases.

EQ Credit 6: Interior lighting

The interior lighting specifications for the two cases were not available. If the BIM model included the lighting design lighting, a schedule per room could have been provided to report compliance through option 2, lighting quality.

EQ Credit 7: Daylight

Calculations using Revit lighting plug-in for $sDA_{300/50\%}$ and $ASE_{100/250}$ resulted in no compliance through option 1 in the two cases for the identified regularly occupied spaces as reported for Miljöbyggnad. The percentage of the complied area did not reach the points threshold of at least 55% for one point (Table 14).

TABLE 14: SDA/ASE SIMULATION RESULTS FOR THE TWO CASES

	Case 1	Case 2
Area meets sDA % hours in rooms with <20% area above ASE	17%	17%
Area meets sDA % hours	21%	20%
Rooms area meets sDA > 55%	11%	3%
Rooms area meets sDA > 75%	8%	3%

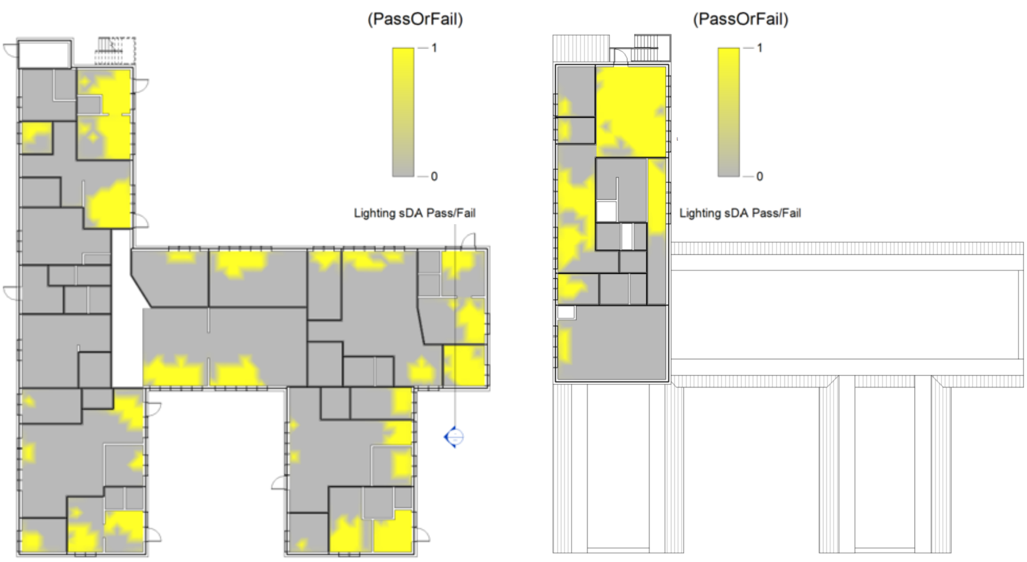

FIGURE 7: CASE 1 ALMGÅRDEN SCHOOL BUILDING sDA SIMULATION RESULTS

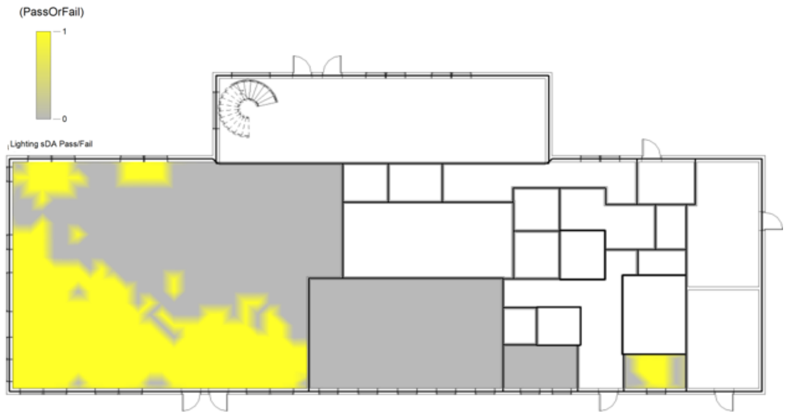

FIGURE 8: CASE 2 STRÖMSBRO SCHOOL BUILDING sDA SIMULATION RESULTS

Simulation of illuminance level between 300 and 3000 lux to follow option 2 of this credit (Table 15), but no points were achieved through that option too. The simulation graphical results for daylight analysis are shown in

Figure 8, Figure 9,

Figure 10 and Figure 10.

TABLE 15: SIMULATION RESULTS OF ILLUMINANCE LEVEL BETWEEN 300 AND 3000 LUX FOR THE TWO CASES

	Case 1			Case 2		
	Passing	Below threshold	Above threshold	Passing	Below threshold	Above threshold
Total Equinox	44%	26%	33%	28%	57%	16%
9:00 am at the Equinox	62%	5%	33%	41%	57%	2%
3:00 am at the Equinox	76%	24%	0%	57%	28%	15%

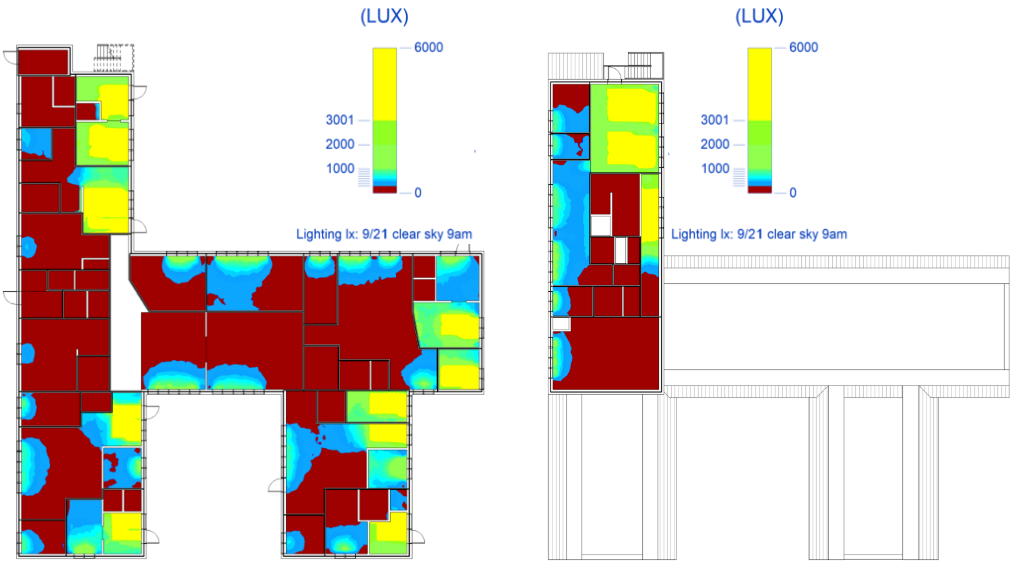

FIGURE 9: CASE 1ALMGÄRDEN SCHOOL BUILDING ILLUMINANCE SIMULATION RESULTS

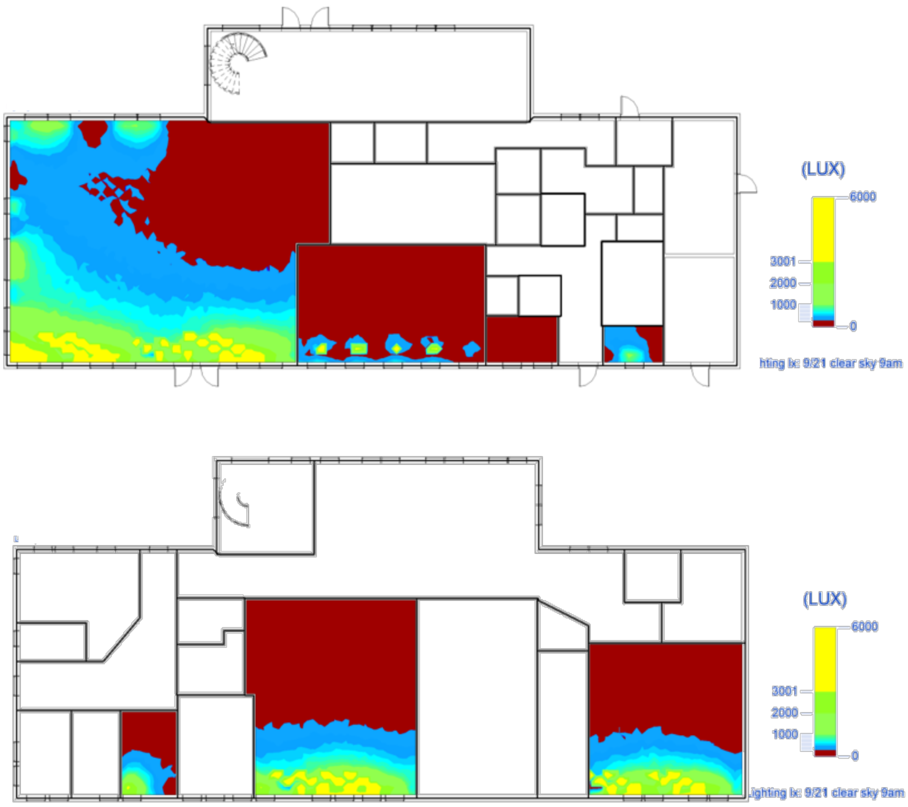

FIGURE 10: CASE 2 STRÖMSBRO SCHOOL BUILDING ILLUMINANCE SIMULATION RESULTS

EQ Credit 8: Quality views

Regularly occupied spaces in both cases have direct line of sight to outdoors through windows. There is no tool that directly calculate the percentage area with outdoor direct sight in the BIM authoring tool. Some commercial analysis tools have a customized solution for the calculation. A work around with Revit space separator tool and a customized schedule can help in documenting the space percentage area. Results are shown in Table 16 and Appendix C.

TABLE 16: PERCENTAGE OF REGULARLY OCCUPIED SPACES WITH DIRECT LINE OF SIGHT

Case 1: Almgården school

No.	Regularly Occupied Space	Space Area (m^2)	Area with Direct Line of Sight (m2)	Horizontal View at 1.07 meters	%	Compliant Area (m2)
110	KONTOR	23	22.5	Yes	98%	23
112	MATSAL / ALLRUM	29	29.0	Yes	100%	29
113	TILLGANGSKOK	30	29.1	Yes	97%	30
122	ALLRUM	58	53.9	Yes	93%	59
204	PERSONALRUM	45	44	Yes	99%	45

Case 2: Strömsbro school

No.	Regularly Occupied Space	Space Area (m^2)	Area with Direct Line of Sight (m2)	Horizontal View at 1.07 meters	%	Compliant Area (m2)
8	Exp. Kitchen	5	4.7	Yes	94%	5
10	Kitchen	57	56.4	Yes	99%	57
15	Dining Room	191	191.0	Yes	100%	191
18	Vegitable Room	8	7.8	Yes	98%	8
32	Music	60	59.4	Yes	99%	60
28	Library	84	81.5	Yes	97%	84
30	Office_1	12	11.4	Yes	95%	12

EQ Credit 9: Acoustic performance

The acoustic design reports for the two cases described the compliance of both building with the local standard SS 2568:2007 and achieved SILVER rating in Miljöbyggnad. Compliance with The Swedish Public Health Agency's general recommendation for indoor noise (FoHMFS 2014:13) and local regulations for preschool buildings limits noise from HVAC equipment to a maximum of 30 dB in regularly occupied spaces for teaching. Regardless of the nature of the noise, permanent sound pressure levels at low frequencies shall be limited to the values of FoHMFS. These conditions meet LEED requirement for schools of this credit.

4.2 LEED and Miljöbyggnad rating comparison

Each rating system has its own goals, structure, and contents. Although it is difficult to fully compare the two systems, there are several similarities in the assessed indicators in terms of the issues and parameters assessed. Table 17 is showing an attempt to compare the potential LEED credits score and achieved Miljöbyggnad indicators' rating for the two studied cases. LEED prerequisites were excluded because of the different structures of the two systems with Miljöbyggnad having no such prerequisites, except for EQp1 Minimum IAQ performance which is similar to the Ventilation indicator in Miljöbyggnad.

TABLE 17: A COMPARISON BETWEEN LEED CREDITS POINTS AND MILJÖBYGGNAD INDICATORS RATING FOR ENERGY AND INDOOR ENVIRONMENT, WITH THE SIMILAR CREDITS ALIGNED AND HIGHLIGHTED

				Case 1		Case 2	
	No. LEED credits	No.	Miljöbyggnad indicators	LEED points	MB. Rating	LEED points	MB. Rating
Energy		1	Heat power demand		GOLD		SILVER
		2	Solar heat load		GOLD		GOLD
	EAc1 Enhanced Commissioning			4		4	
	EAc2 Optimize Energy Performance	3	Energy use	6	GOLD	6	GOLD
	EAc3 Advanced Energy Metering			1		1	
	EAc4 Demand Response			0		0	
	EAc5 Renewable Energy Production	4	Share of renewable energy	2	GOLD	0	SILVER
	EAc6 Enhanced Refrigerant Management			0		0	
	EAc7 Green Power and Carbon Offsets			2		2	
			Category rating	15/31	GOLD	13/31	SILVER
Indoor Environment		6	Radon		BRONZE		SILVER
		8	Moisture safety		SILVER		SILVER
		12	Legionella		SILVER		SILVER
	EQp1 Minimum Indoor Air Quality Performance	7	Ventilation	Required	SILVER	Required	SILVER
	EQc1 Enhanced Indoor Air Quality Strategies			2		2	
	EQc2 Low-Emitting Materials			0		0	
	EQc3 Construction IAQ Management Plan			0		0	
	EQc4 Indoor Air Quality Assessment			0		0	
	EQc5 Thermal Comfort	9 &10	Winter & Summer Thermal comfort	1	SILVER/BRONZE	1	SILVER/BRONZE
	EQc6 Interior Lighting			0		0	
	EQc7 Daylight	11	Daylight	0	BRONZE	0	GOLD
	EQc8 Quality Views			1		1	
	EQc9 Acoustic Performance	5	Sound	1	SILVER	1	SILVER
			Category rating	5/16	SILVER	5/16	SILVER

For LEED EA category, the potential points achieved is about half of the available points while there are some credits were not pursued because of information lack for the case buildings. LEED is addressing more credits in this category than Miljöbyggnad and considering the impact of energy cost in the projects.

In the Indoor environment category, the two rating systems has more similarities, but LEED gave more additional categories to focus in AIQ and interior lighting while Miljöbyggnad assessing different aspects such as Radon, moisture, and Legionella.

When it comes to the final rating in both systems, LEED is assessing more categories that have significant environmental impact extended to the site and its surroundings.

5 Discussion

5.1 BIM for energy analysis

The implementation of BIM for energy analysis and in building environmental assessment and certification is increasing in the AEC industry and has been realized in research. In agreement with the reviewed previous studies, this study proved that BIM is beneficial for environmental certification process. In this study, the review of previous studies reflected the global interest in the technology and presented some improvements to overcome the implementation of BIM especially in the early stages of design and encourages the integrative design process. There are important factors affecting the adoption of BIM that were not discussed in depth in previous studies such as competency, training, and adoption of BIM from the AEC companies' perspective. Companies need to invest in both the software and people for an effective and beneficial implementation and automation of time-consuming manual work. Research could provide the industry with the necessary guidance and the proper highlight to all sides of the subject for the successful implementation.

Several tools are available for model energy analysis with capabilities to evaluate and compare different design options. Autodesk Insight, the cloud tool was used because of the ability to start use it early in the design to inform the whole design about the effect of important considerations influencing the energy use to act on them. The tool is not presenting the details of the ASHRAE 90.1 model which is the chosen benchmark. Autodesk Revit is now integrating EnergyPlus engine to provide detailed energy analysis but there is a need for more improvement to how the user can control the input and settings. Unless the software become user-friendly, engineer will resist the adoption. That might also be the reason that energy engineers are biased to the tools that they are familiar to. Integrating the stand-alone analysis software into the BIM workflow would be much appreciated by professionals. Standardization and interoperability are crucial for this process and would solve the feedback issue from the stand-alone programs.

Although the study found that EnergyPlus and DesignBuilder programs has more frequency in studies from different part of the world, IDA-ICE was used in this study to perform energy and indoor environment analysis. The software is the norm in Sweden and widely present in Europe. IDA-ICE has s module to provide the calculations according to BBR and another for Miljöbyggnad with the expert version equipped with a module that automatically perform the calculation according to ASHRAE 90.1 Appendix G. The program is flexible and user-friendly with a lot of detailed analysis that needs detailed input. The process of data exchange was challenging. The software can import IFC format, but the file should be simplified to only contain the supported elements which are spaces, walls, windows, and slabs.

Only space name is supported by IDA-ICE while construction type for walls, windows and slabs could be mapped to the IFC types. The exported IFC model from Revit must be checked and validated to avoid interoperability problems. For walls, identification as an internal or external wall is important and must be checked if that was inherited from the BIM file. All walls and windows must belong to a story in the building as walls extending through building stories are not supported by IDA-ICE. Curtain walls are not detected as transparent by IDA-ICE and must be handled before running the analysis. In case 2 Strömsbro school building, the stairs curtain wall was modelled as windows and went smoothly into IDA-ICE. Shading objects are not supported and must be modelled in IDA-ICE. The building body was detected by IDA-ICE, but there was a problem with modelling the roof in levels that have occupied spaces and a roof in other parts of the building at the same time such as case 1 Almgården school building where the second floor has spaces in part of the building while this level is the roof of the other parts of the building.

5.2 BIM in environmental assessment tools

LEED was found to be the most used to demonstrate the BIM implementation for green building certification. This could be because of the widespread of the rating system. Green Building Councils (GBCs) exist in every region around the world supporting LEED rating system development and participate in identifying regional priorities. Efforts from regional GBCs gave the rating system a great push into regional markets by providing technical explanations and studies to support the adoption of local standards and clarifying local priorities to be included as an equivalent to U.S. rating system certification requirements. The collaboration of GBCs could avail useful and diverse experiences from scientists and professionals from different regions to the rating system and its consensus.

As this study is using two Miljöbyggnad certified buildings, it was of interest to search for previous studies about BIM implementation in Miljöbyggnad certification. A search was carried out in EBSCO and ScienceDirect with the keyword "BIM Miljöbyggnad". The search did not find studies that are focusing on the specific subject of BIM application in Miljöbyggnad. EBSCO search did not show any results. ScienceDirect showed only three results, one of them (Sadri, et al., 2022) is discussing Boverket's Climate Declaration Act and the second (Ascione, et al., 2022) is reviewing different building rating systems. Both articles only mentioned Miljöbyggnad among others and BIM as an integrated method. The third study (Javanroodi, et al., 2019) is proposing a design framework to enhance energy efficiency in high-rise buildings in urban areas by integrating BEATs aspects and parameters into the framework. Another search through Google Scholar with the same keywords shows returned with several master's thesis work (Niemi & Sande, 2015; Widell, 2013; Burman & Thrysin, 2011) that studied the implantation of BIM in environmental assessment certifications in general without the focus in the specific indicators' application. Another two theses discussed BIM for Miljöbyggnad's material indicator were found (Blomberg, 2018; Buszman & Canel, 2014).

5.3 BIM in the cases studied

The generated BIM model was used in EA credits in the energy and atmosphere category. In the EQ category, the model was used in IAQ credits, thermal comfort, interior lighting, daylight, and quality views credits.

5.3.1 BIM in EA credits

Energy use is a large part of the building environmental assessment evaluation. The BIM workflow provides energy analysis solutions with less effort and time to fulfil the documentation requirements of the certification tools. Apart from energy use, BIM provides other analysis and simulation tools. The insight tool was helpful in complying with the EAp2 Minimum energy performance by allowing the demonstration of different design options and their impact on energy use. This step is complying with the Integrative Design process as the important overall LEED certification requirement. The insight tool has limited choices of HVAC system types and no control over energy price input. The creation of the energy analytical model is done by Revit before sending it to Insight. Some errors may occur in the analytical model conversion, and it must be checked thoroughly for the analysis's accuracy. The tool is useful in the early stages of design but the detailed energy analysis of the two cases in IDA-ICE with full control over the inputs and more options for the output provided more assistance in evaluating the certification parameters.

Case 1 Almgården school building's energy performance has achieved a high rating in both LEED and Miljöbyggnad. The Insight tool result reflected the best practices that have been used in most of the design options by showing the modelled options granted better energy use results. In case 2, the ASHRAE 90.1 model was close to the design energy use.

5.3.2 BIM in EQ credits

The model simulation of the indoor air quality and thermal comfort indices has stipulated room-by-room values throughout the calculation year. An optional output in IDA-ICE is the representation of the compliance with standard EN 15251. Both LEED and Miljöbyggnad provide Excel templates for calculation and reporting. The BIM software can export reports and schedules to Excel format which will avail analysis reports and schedules to be edited and facilitate the reporting of the IAQ and ventilation requirements. The same could be done to report the interior lighting with option 2 of the credit.

All the required parameters for daylighting in both LEED and Miljöbyggnad can be simulated with BIM tools. LEED requires the simulation of sDA, SAE and illuminance while Miljöbyggnad requires the Daylight Factor (DF) and glass area to floor area ratio (AF). The LEED requirements for daylight credit are stringent and need to be taken care of early in the building design, The ASE is considered to evaluate the risk of glare, so shades and blinds should be included in the model to prevent sun glare effect on the building's glazing. The requirement for option 1 has been reduced in LEED v4.1 to reward the achievement of 40% of the area of the regularly occupied spaces in option 1 and 50% for option 2.

The improvement of BIM tools by their developers continue to provide more solutions to be used in the certification process. Users are also trying to make new techniques using the existing software features or through BIM programming tools to help in green building certification, like the one used in Quality vies credit. Several solutions provided as on-demand cloud services.

5.3.3 LEED and Miljöbyggnad rating

Each building environmental assessment tools is addressing the environmental issues differently. Miljöbyggnad reflects the priorities in Sweden by introducing a system that focuses in important areas that guarantee the best performance of sustainable buildings. LEED is allowing the use of USGBC approved equivalent local standards and provided compliance path for projects outside the U.S. The systems differ in many ways such as the issue assessed, the rating method and how the project boundaries are defined. Despite the differences there are several similarities in the assessment aspects.

The energy use in LEED is requires whole-building energy calculation in kWh/m^2 while the Miljöbyggnad the calculation is done according to BBR method in $kWh/m^2.A_{temp}$ which include the space heating, cooling (if used), domestic hot water and facility energy and exclude the household electricity use and process energy.

The LEED rating system has special guidelines to achieve points in school projects. The Minimum Acoustic Performance prerequisite in LEED is only applied in school projects.

To achieve the final rating in LEED, the project must include more categories such as location and transportation (L&T), and Water efficiency which are important aspects for a sustainable development. With LEED allowing the use of local codes and standards, the building can be designed and assessed according to the local codes and get assessment results that can be compared globally as well as to buildings in similar climate conditions. The global adoption of LEED by the Sweden Green Building Council would assist in providing local compliance support and provide education to avail more competence to the market.

BIM could be applied to several Miljöbyggnad indicators like the applications presented for LEED credits. IDA-ICE has a module for Miljöbyggnad indicator's calculation and recommended by the guidelines.

6 Conclusion

6.1 Study results

BIM adoption increased within the last twenty years in the AEC industry as a part of the digital transformation that is happening in all industries. The building sector is one of the largest energy consumers and there are global efforts toward sustainable and energy efficient new buildings and retrofitting the existing ones. Regulations are in action globally to improve building efficiency and prevent the negative impact on natural resources. Regulations only set the minimum performance parameters considering the economic consequences on the industry when implanting efficiency solutions. To take those efforts further, the building environmental assessment tools such as LEED and Miljöbyggnad have been introduced as voluntary tools to transform the market and promote the sustainability in buildings by rating their performance.

LEED is the most popular rating system globally and Miljöbyggnad is most used in Sweden because of the concentration in local priority issues to meet and exceed the local codes and standard. LEED popularity could be due to the flexibility of using local codes and the availability of local certification support through Green Building Councils.

The application of BIM in environmental assessment was practiced and studied following the increasing number of projects adopting the BIM workflows and pursuing green building certifications and it proved to be advantageous. Some of the identified advantages are collaboration, accuracy, time, and cost saving. The architectural 3D model being in the center can be referenced to create work sets with suitable information for other disciplines and teams to collaborate and add their work to the BIM environment, The collaboration will be followed through the project's phases which promote the integrative process. The use of BIM to model and simulate the design increases the accuracy of the results by utilizing the right information about the building elements and systems. BIM implementation cut the time taken for evaluating and documenting credit requirements with traditional manual work which cut the costs of the design and construction. Construction cost savings are also involved when design options are evaluated, and changes are made before construction starts.

Many challenges are facing the application of BIM in the certification process such as data exchange issues, knowledge, and the differences in assessment tools. The stand-alone analysis tools support specific data which is needed for calculations while the architectural model could be packed with a huge number of details that must be reduced and simplified for better results. The process necessitates the use of middleware. The IFC and gbXML schemas are developing to overcome the interoperability issues and the customization of the exported data, but different analysis software use engines and that could be addressed by standardization of data exchange. The standardization effort should include the feedback process from the analysis software to the BIM authoring tool to complement the central BIM models with the analysis result. The human resource and user's knowledge play a crucial role in the application of BIM in an organization. Companies hire a BIM manager with multiple skills in CAD, BIM, and Information Technology (IT) to manage the implementation of the workflow and the integration of different tools and teams. Staff training is important for collaboration and implementation success. Automation of the whole process of certification has been discussed in previous studies and it involves programming and database knowledge. This effort, if supported by the authoring tools' developers could produce very useful plug-ins. It can provide a fully automated solution for one certification system due to the different contents of the assessment tools.

The full comparison of different assessment systems is difficult. The framework that compares the scope, structure, content, and aggregation, would give a meaningful comparison. The comparison requires rearranging the rating system indicators into unified categories.

Energy use constitutes a considerable part of every assessment and rating system. The BIM software can be used directly in energy analysis using the integrated modules within the popular authoring tools or by transferring the model data to a stand-alone tool. The energy plug-ins of the authoring tools such as Revit are still lacking full control over the analytical model and the limited input options. More green building indicators evaluation and reporting could benefit from software providers and user's innovation.

The early adoption of BIM in the evaluation from the conceptual design is the best approach to achieve better performance and will improve each following phase of building projects.

6.2 Outlook

Software and IT is fast developing technologies and plays an important role in the digital transformation of the AEC industry. A multidisciplinary approach is needed to provide solutions that facilitate the integration of green building assessment and certification aspects into the design and construction practice. More research in the programmatic solutions to create new tools and techniques to automate the building environmental assessment. If supported by the software providers and promoted by the organizations administering the certification, this type of research will pave the way for solutions that save time and costs leading to the production of highly efficient buildings.

The use of BIM can be extended to the operation phase of the building. The trending technology of the Internet of Things (IoT) together with the continuously developing wireless communication and sensors can be used to feed real-time information for the purpose of measurement and verification or for facility management.

6.3 Perspectives

Fostering innovation in technologies such as building information modelling and pursuing environmental certification serves the buildings and infrastructure's sustainability goals. Better building design and construction will accelerate the achievement of reducing the impact of building on natural environment and energy resources by providing time and cost saving solutions for building design and assessment. Refining the design can result in better building environment that ensure the good health and well-being of occupants and provide decent work conditions and economic growth.

To achieve the targets of reducing the emission from the generated energy that supply our buildings, the sustainability of the newly produced and existing buildings' energy use must be addressed. Positive or nearly-zero buildings are tough targets, so more efforts and innovation must be employed. Building modelling and certification would contribute to the responsible energy use while promoting the use of affordable clean energy.

The use of BIM and environmental assessment tools in budling and infrastructure design is boosting the movement toward smart sustainable cities and communities.

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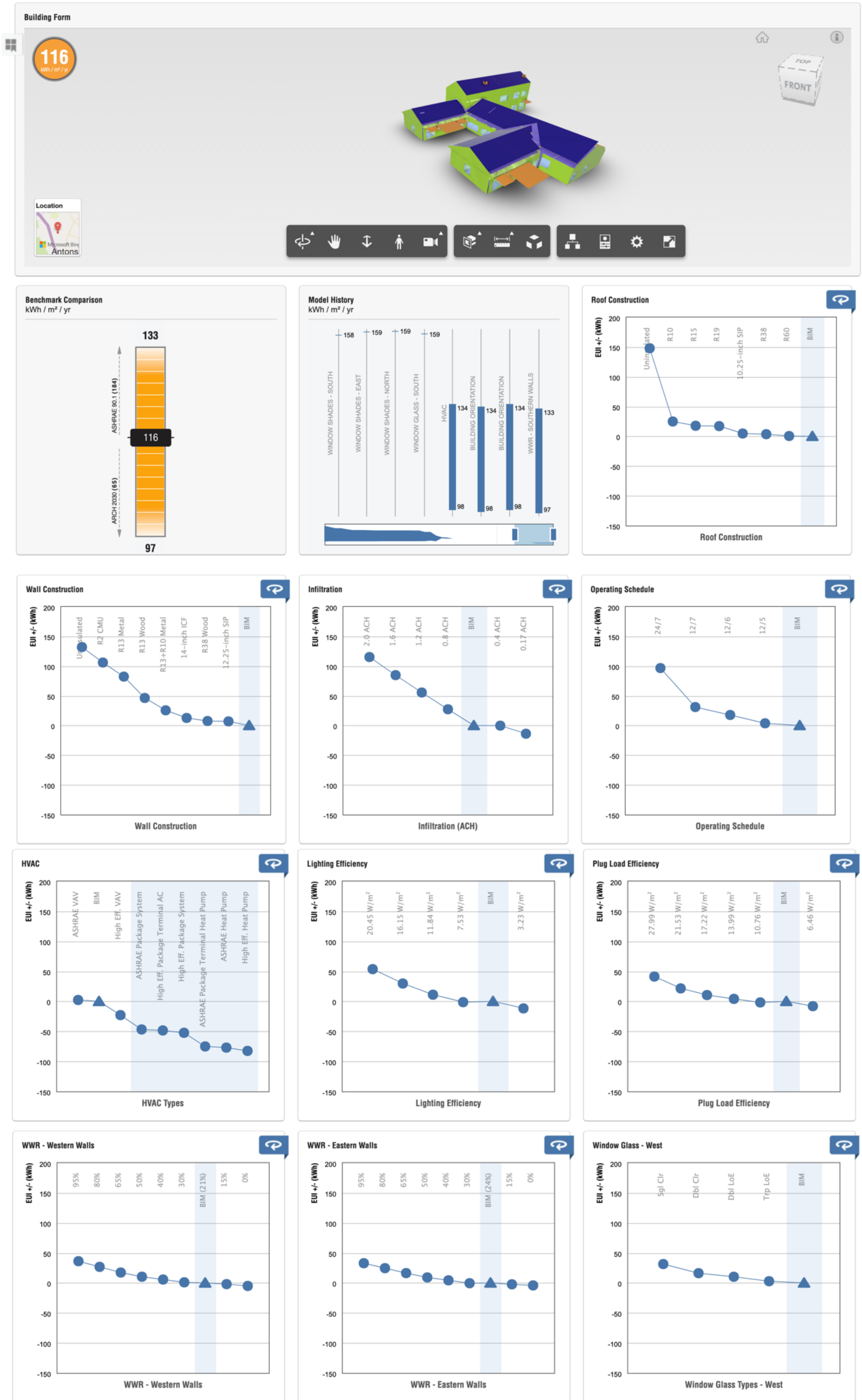
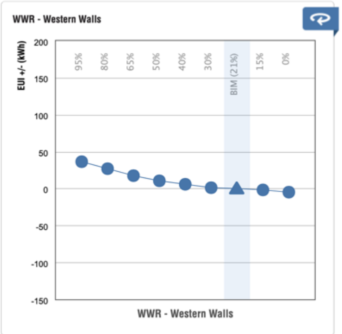
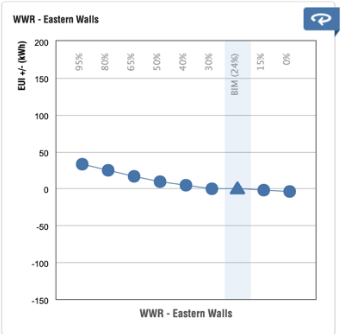
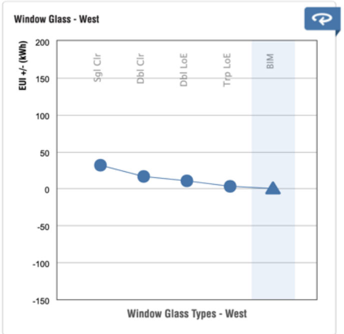
Appendix A

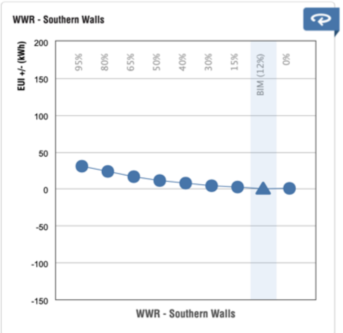
Case 1: Almgården school building Insight results and comparison

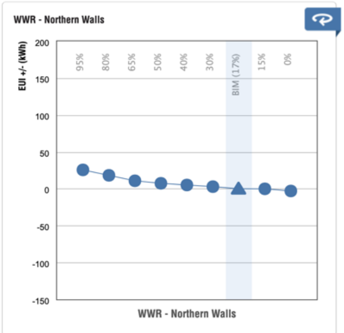


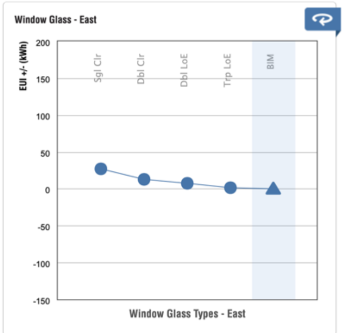

WWR - Western Walls
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
95%
80%
65%
50%
40%
30%
BIM (21%)
15%
0%
WWR - Western Walls

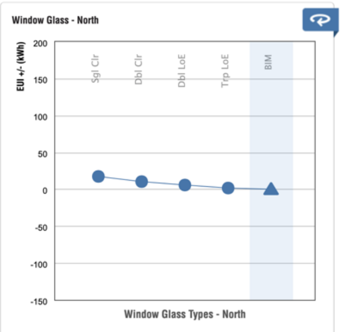

WWR - Eastern Walls
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
95%
80%
65%
50%
40%
30%
BIM (24%)
15%
0%
WWR - Eastern Walls

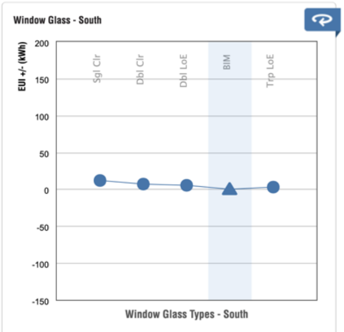

Window Glass - West
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
Sgl Clr
Dbl Clr
Dbl LoE
Trp LoE
BIM
Window Glass Types - West

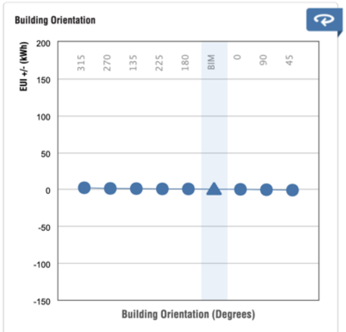

WWR - Southern Walls
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
95%
80%
65%
50%
40%
30%
15%
BIM (12%)
0%
WWR - Southern Walls

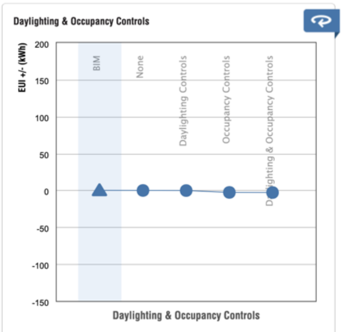

WWR - Northern Walls
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
95%
80%
65%
50%
40%
30%
BIM (17%)
15%
0%
WWR - Northern Walls

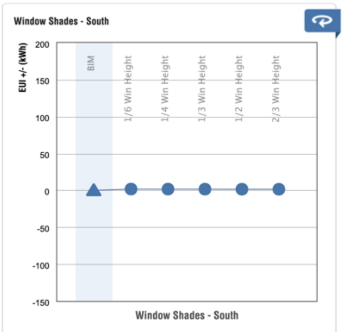

Window Glass - East
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
Sgl Clr
Dbl Clr
Dbl LoE
Trp LoE
BIM
Window Glass Types - East

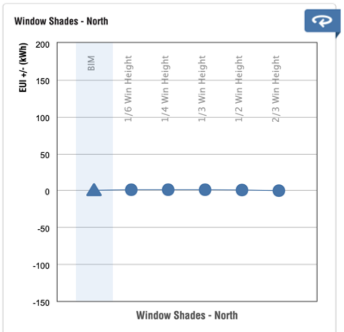

Window Glass - North
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
Sgl Clr
Dbl Clr
Dbl LoE
Trp LoE
BIM
Window Glass Types - North

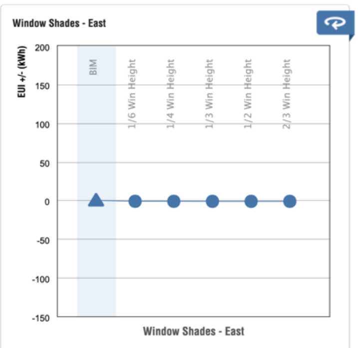

Window Glass - South
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
Sgl Clr
Dbl Clr
Dbl LoE
BIM
Trp LoE
Window Glass Types - South

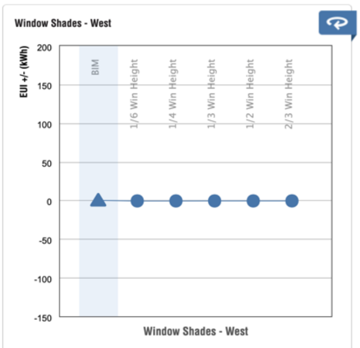

Building Orientation
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
315
270
135
225
180
BIM
0
90
45
Building Orientation (Degrees)


Daylighting & Occupancy Controls
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
BIM
None
Daylighting Controls
Occupancy Controls
Daylighting & Occupancy Controls
Daylighting & Occupancy Controls

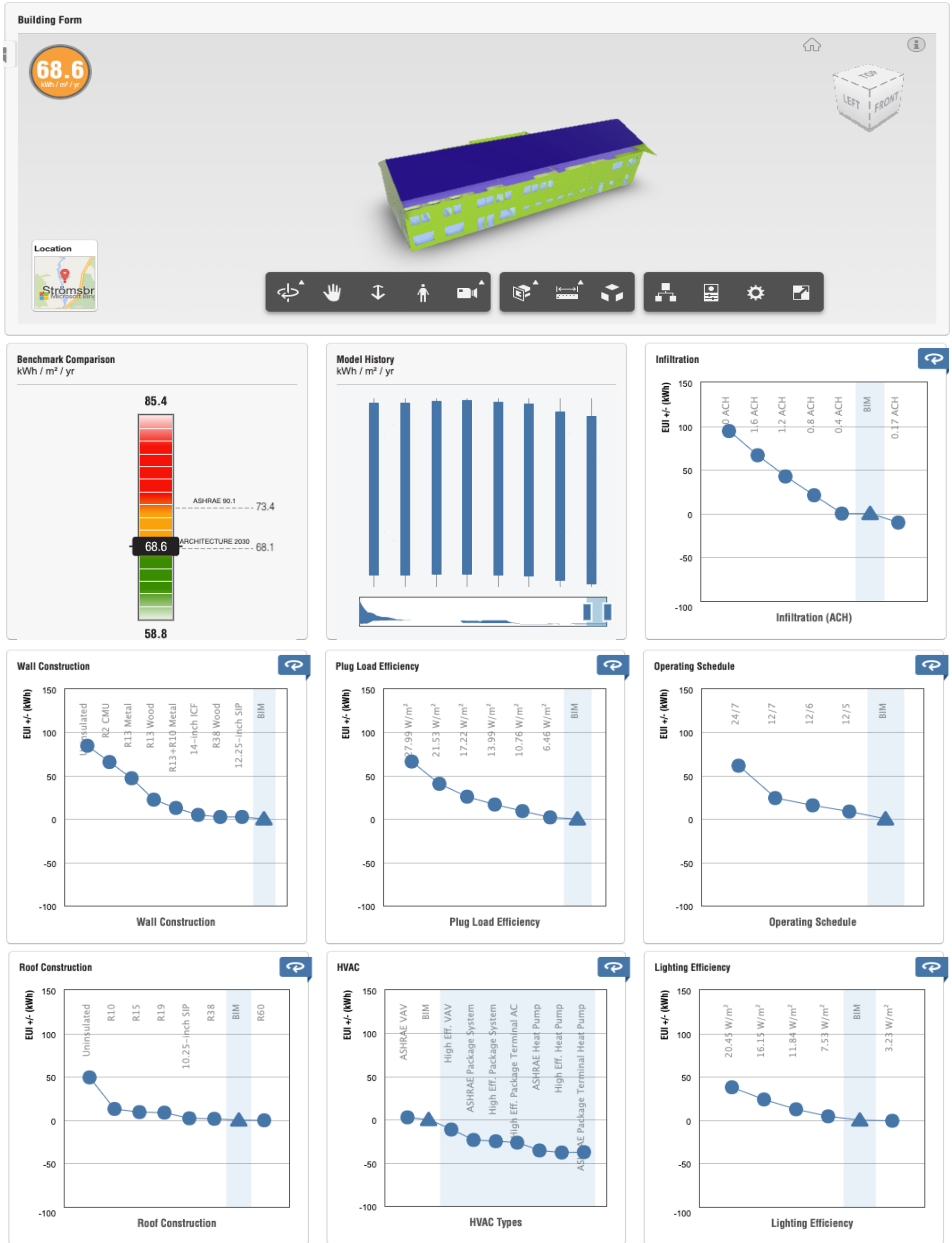

Window Shades - South
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
BIM
1/6 Win Height
1/4 Win Height
1/3 Win Height
1/2 Win Height
2/3 Win Height
Window Shades - South

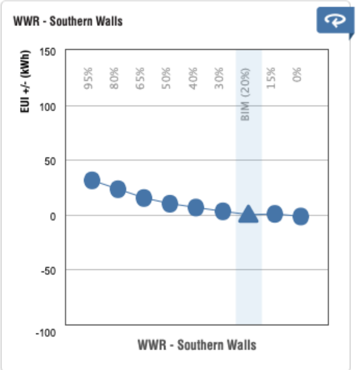

Window Shades - North
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
BIM
1/6 Win Height
1/4 Win Height
1/3 Win Height
1/2 Win Height
2/3 Win Height
Window Shades - North

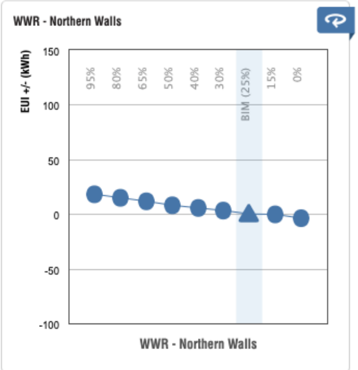

Window Shades - East
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
BIM
1/6 Win Height
1/4 Win Height
1/3 Win Height
1/2 Win Height
2/3 Win Height
Window Shades - East

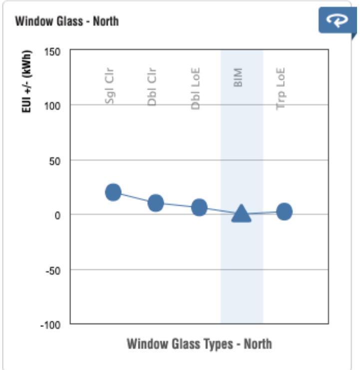

Window Shades - West
EUI +/- (kWh)
200
150
100
50
0
-50
-100
-150
BIM
1/6 Win Height
1/4 Win Height
1/3 Win Height
1/2 Win Height
2/3 Win Height
Window Shades - West

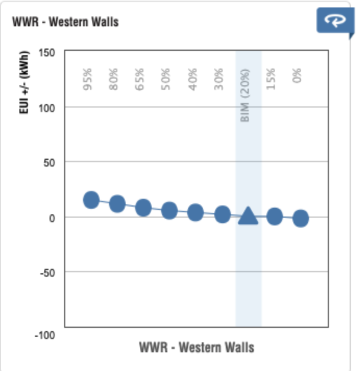
Case 2: Strömsbro school building Insight results and comparison

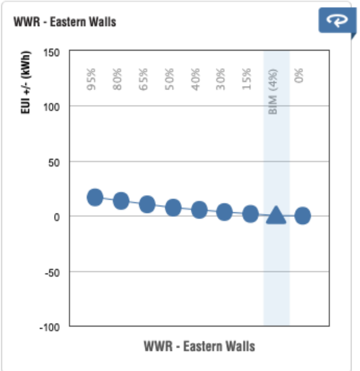


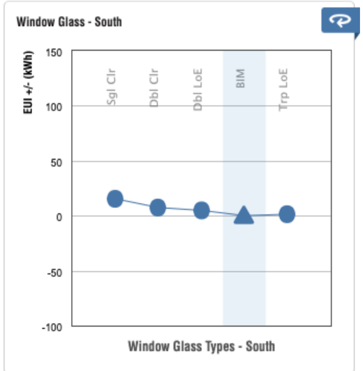


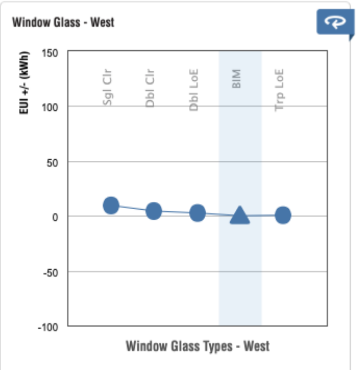


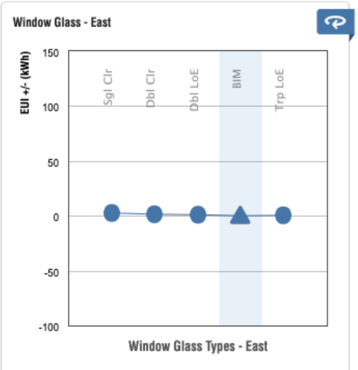


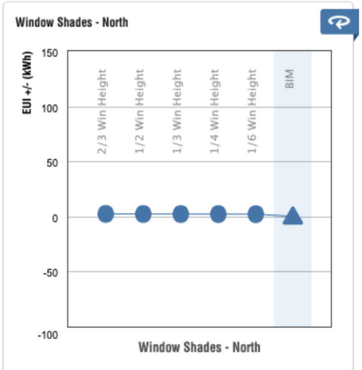


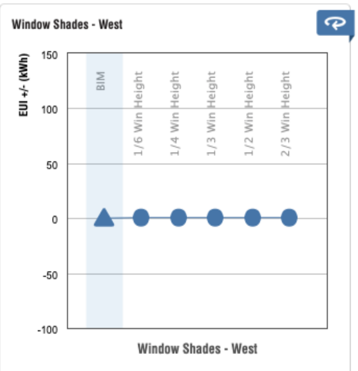


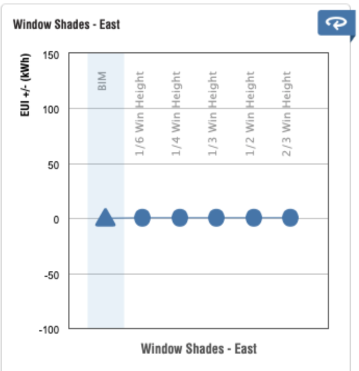












PV - Panel Efficiency

The percentage of the sun's energy that will be converted to AC energy. Higher efficiency panels cost more, but produce more energy for the same surface area.

Current Setting:
16 %

Appendix B

Case 1: Almgården school building IDA-ICE IAQ results

Zone	Min temp, °C	Max temp, °C	Min op temp, °C	Max op temp, °C	Max sup airflow, L/(s m2)	Max rtn airflow, L/(s m2)	Max rel hum, %	Max CO2, ppm (vol)	Max PPD, %
142 ALLRUM	21.85	28.59	21.96	27.28	2.874	2.842	74.74	721.3	13.09
123 ALLRUM	21.83	27.17	21.95	26.66	3.053	3.021	73.92	559.7	12.09
122 ATELJE	21.93	27.58	21.94	27.37	4.077	4.036	74.77	950	13.84
120 DISKRUM	21.04	26.29			23.95	23.76	77.51	400	
111 DRAMA/DANS	21.91	27.54	21.97	27.36	5.65	5.609	75.1	950	13.92
ELEC18-1	21.75	24.99			5.102	5.052	75.79	400	
101 ENTRE PERSONAL	21.95	27.4			0.5607	0.5548	72.63	400	
150 FORRAD	20.11	25.55			4.83	4.812	77.9	400	
134 FORRAD	21.76	25.17			3.006	2.975	76.19	400	
131 FORRAD	21.77	25.1			3.157	3.127	75.7	400	
146 GROVENTRE	21.82	26.39			1.896	1.877	75.87	400	
139 GROVENTRE	20.87	26.43			1.947	1.933	78.41	400	
128 GROVENTRE	21.86	26.3			1.451	1.436	75.29	400	
107 GROVENTRE	21.85	26.83			1.932	1.912	75.16	400	
138 KAPPRUM	20.87	29.04			1.947	1.933	76.33	400	
127 KAPPRUM	21.85	27.59			1.451	1.436	75.36	400	
106 KAPPRUM	21.83	29.1			1.933	1.913	74.11	400	
110 KONTOR	21.67	26.48	22.25	26.21	5.105	5.051	73.93	644.7	10.7
119 KYLRUM	21.7	24.69			5.532	5.478	76.02	400	
117 OMKL	21.7	24.91			5.634	5.58	75.86	400	
103 OMKL	21.69	25.9			4.739	4.692	75.63	400	
114 RENSERI	21.69	24.84			5.53	5.476	76.01	400	
145 Room	21.82	30.43			1.897	1.877	74.25	400	
147 Room	21.84	24.82			1.896	1.876	74.37	400	
137 Room	21.84	25.4			1.946	1.926	75.35	400	
102 KONTOR	21.62	29.65	22.24	26.69	6.854	6.786	74.29	530.9	10.76
140 RWC	21.81	25.05			1.947	1.926	75.57	400	
132 RWC	21.75	25.07			3.159	3.127	76	400	
143 SKOTRUM	21.9	29.74	22.09	29.61	2.875	2.836	74.81	1536	44.48
125 SKOTRUM	21.6	25.96	22.16	24.76	5.991	5.932	77.5	479.6	10.95
105 STAD/TVATT	21.74	25.76			4.33	4.287	74.54	400	
113 TILLGANGSKOK	21.32	26.31	22.28	24.99	13.22	13.1	77.63	436.6	9.356
116 TORRVAROR	21.78	24.91			4.002	3.964	75.22	400	
UC-1	12.75	27.29			1.496	1.528	91	400	
115 VARUMOTTAGN	21.71	25.27			4.003	3.963	75.48	400	
149 VERKSTAD	21.94	28.68			4.604	4.56	72.37	400	
135 VERKSTAD	21.96	27.21			6.405	6.375	72.96	400	
124 VERKSTAD	21.94	27.09	21.94	26.8	3.921	3.884	74.01	950	11.94
130 VILRUM	21.76	29.15	22.21	27.82	3.181	3.149	73.52	557.9	16.71
148 VILRUM/GRUPPRUM	21.63	30.39	22.29	26.27	5.897	5.839	74.15	496.2	10.43
141 VILRUM/GRUPRUM	21.58	30.08	22.27	26.01	6.923	6.856	75.18	481.3	10.27
144 WC	21.85	25.15			1.896	1.877	76.13	400	

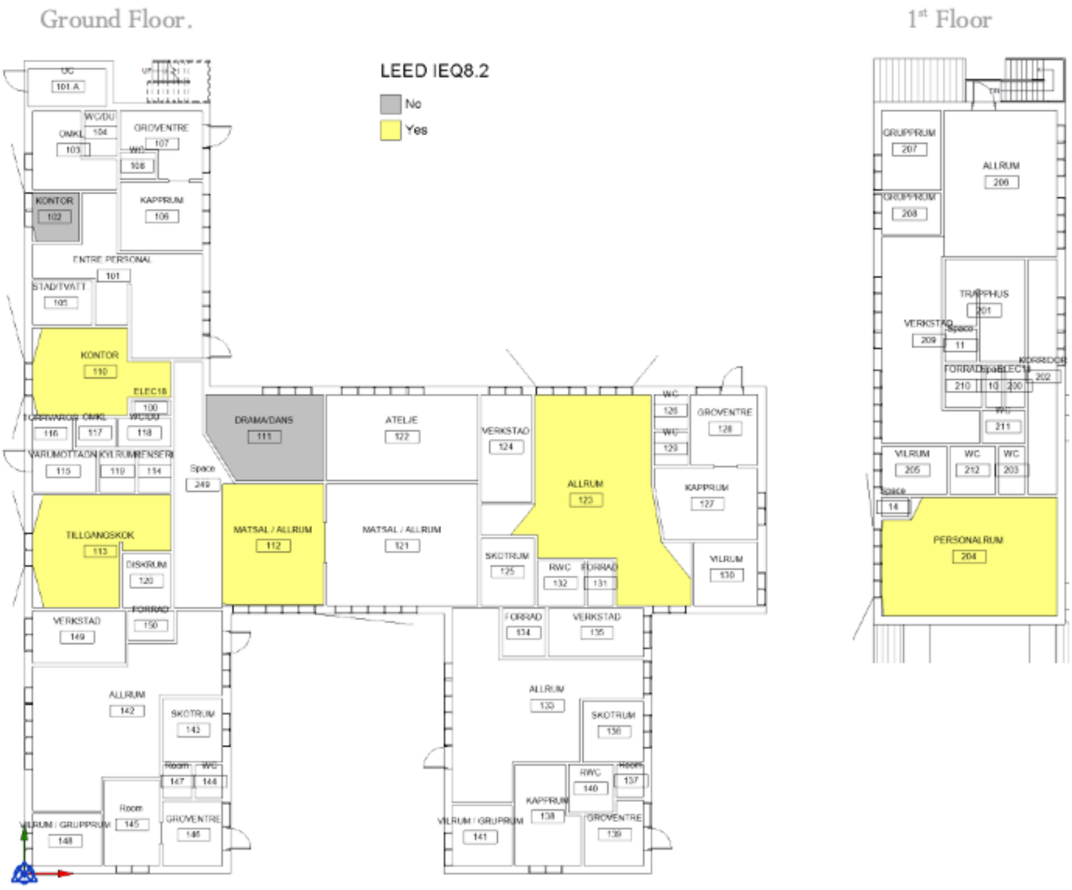
129 WC	21.87	24.94			1.451	1.436	75.02	400	
126 WC	21.88	25.56			1.45	1.435	75.33	400	
108 WC	21.85	25.82			1.932	1.912	73.37	400	
118 WC/DU	21.69	24.79			5.639	5.581	76.33	400	
104 WC/DU	21.71	25.53			4.738	4.691	76.05	400	
206 ALLRUM	21.79	28.66	21.85	28.68	3.142	3.105	72.63	717.3	26.73
ELEC18-2	21.76	25.8			3.109	3.077	73	400	
210 FORRAD	21.73	25.84			3.11	3.079	72.62	400	
208 GRUPPRUM	21.95	31.29	21.84	27.42	7.431	7.323	70.76	2599	13.81
207 GRUPPRUM	21.94	28.91	21.83	26.51	5.676	5.612	71.89	949.9	12.58
202 KORRIDOR	21.9	29.68			0.8847	0.8754	72.76	400	
LIFT-2	21.9	26			0.8847	0.8756	70.23	400	
SHAFT-3	21.99	25.8					12.1	390.8	
201 TRAPPHUS	21.91	26.19			0.8849	0.8755	70.34	400	
209 VERKSTAD	21.8	30.92	21.86	27.93	3.143	3.107	71.93	782.8	18.14
205 VILRUM	21.61	29.58			4.367	4.325	73.32	400	
212 WC	21.62	25.83			5.195	5.145	75.05	400	
211 WC	21.6	26			6.419	6.358	75.43	400	
203 WC	21.65	25.86			5.195	5.146	75.14	400	
FLAKTRUM	18.64	26.29			0.352	0.3519	68.93	400	
TRAPPHUS-3	21.83	25.98			1.437	1.422	71.82	400	
121 MATSAL/ALLRUM-merged	21.07	28.99	21.48	27.48	3.076	3.049	75.46	996.5	14.77
136 SKOTRUM-merged	21.84	27.73	21.98	26.95	3.144	3.109	74.84	721.8	11.64
204 PERSONALRUM-merged	21.77	27.32	22.03	26.2	2.012	1.992	72.36	606.7	11.89

Case 2: Strömsbro school building IDA-ICA IAQ results

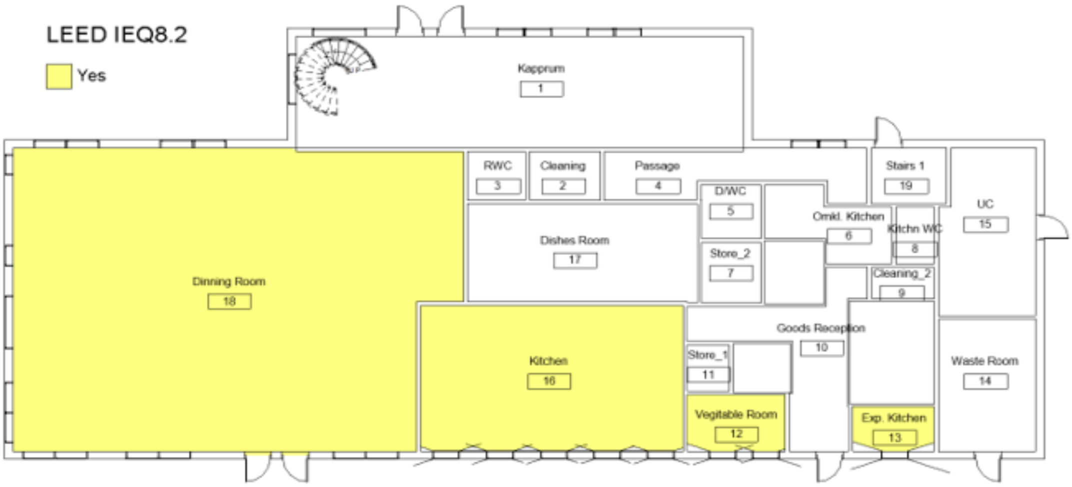
Zone	Min temp, °C	Max temp, °C	Min op temp, °C	Max op temp, °C	Max sup airflow, L/(s m2)	Max rtn airflow, L/(s m2)	Max rel hum, %	Max CO_2, ppm (vol)	Max PPD, %
Cleaning	20.98	23.41			0.3515	0.3495	75.33	400	
Cleaning_2	20.98	23.64	21.32	23.37	0.3514	0.3491	79.79	1247	66.4
D/WC	20.99	22.9			0.3514	0.3494	75.45	400	
Dinning Room	20.89	26.74	21.06	24.92	5.823	5.792	75.59	765.8	70.6
Dishes Room	20.8	23.44	21.22	22.98	13.05	12.99	78.6	480.6	69.72
Exp. Kitchen	20.83	23.54	20.97	23.44	3.413	3.394	79.47	511	74.63
Goods Reception	20.83	22.89			4.582	4.557	79.81	400	
Kapprum	20.93	25.63			1.206	1.199	78.14	400	
Kitchen	20.67	24.06	21.14	23.42	25.1	24.99	79.09	437.4	71.75
Kitchn WC	20.97	22.35			0.3516	0.3495	76.93	400	
Omkl. Kitchen	20.86	23			4.302	4.28	78.46	400	
Passage	20.94	23.75			1.148	1.142	78.75	400	
RWC	20.98	23.64			0.3514	0.3494	73.75	400	
Stairs 1	20.98	22.16			0.3516	0.3497	77.51	400	
Store_1	20.99	22.54			0.3517	0.3496	75.91	400	
Store_2	20.99	22.57			0.3515	0.3496	76.3	400	
UC	15.82	22.04			0.3515	2.03	86.88	400	
Vegitable Room	20.86	23.62	21.04	23.59	3.405	3.387	79.64	651.4	73.1
Waste Room	16.82	22.68			2.009	2.024	82.95	400	
Corridor 1	20.95	24.67			0.7378	0.734	75.95	400	
Corridor 2	20.98	25.61			0.3514	0.3495	68.76	400	
Electricity Room	20.88	23.2			3.223	3.206	79.1	400	
Exp. Library	20.88	24.88	21.08	23.95	3.052	3.036	72.26	521	72.49
Fans Room	20.98	22.99			0.3516	0.3496	73.75	400	
Group Room	20.94	27.39	20.94	25.45	4.056	4.002	73.21	730	74.81
Library	20.94	25.07	21.02	25.06	1.727	1.703	75.58	852.2	73.15
Music	20.94	25.08	20.93	25.08	1.977	1.963	78.67	1097	74.29
Music FRD	20.94	22.7			1.047	1.042	78.44	400	
Music GRP	20.94	22.79	20.84	22.56	1.004	0.9986	79.17	478.8	76.39
Office_1	20.87	26.4	20.99	25.15	2.556	2.542	72.64	522.1	74.32
Office_2	20.86	26.81	21.01	25.16	2.98	2.964	72.65	523.3	74.12
Office_3	20.86	30.03	20.93	26.62	2.749	2.734	73.81	522.3	75.17
Rest Room	20.89	26.29			2.468	2.455	74.53	400	
RWC-1	20.94	24.69			1.221	1.213	72.58	400	
School Nurse	20.91	25.97	20.91	24.88	1.585	1.576	73.33	487.3	75.56
Stairs 2	20.96	22.91			0.3516	0.3496	75.25	400	
Stairs 3	20.86	28.48			2.008	1.998	75.8	400	

Appendix C

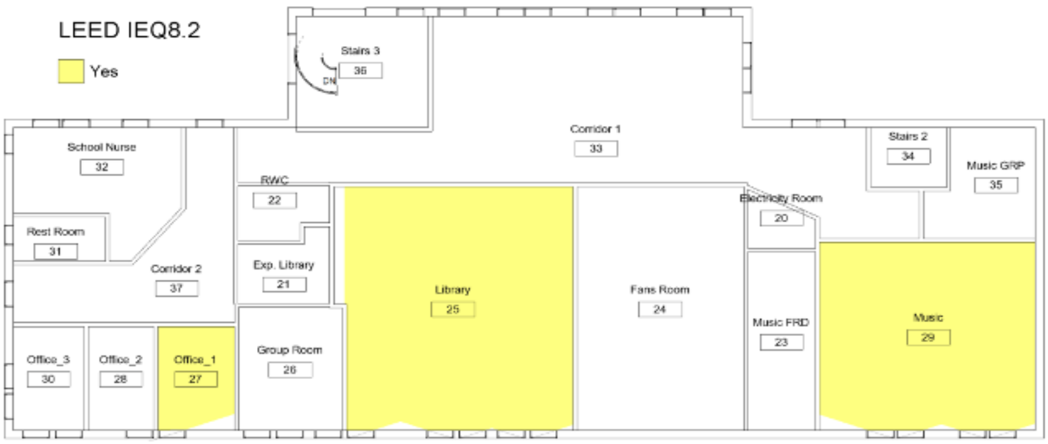
Case 1: Almgården school building direct lines of sight for quality views credit



Case 2: Strömsbro school building direct lines of sight for quality views credit



Ground Floor



1st Floor