SUSTAINABILITY PERFORMANCE INDEX FOR BUILDING ENVELOPE

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by

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CERTIFICATE

This is to certify that the thesis entitled, "**SUSTAINABILITY PERFORMANCE INDEX FOR BUILDING ENVELOPE"** submitted by **Rajat Aggarwal** to Indian Institute of Technology Delhi, for the award of the degree of the **Doctor of Philosophy** is a record of bonafide research work carried out by him. He worked under my supervision for the submission of this thesis, which to the best of my knowledge, has reached the requisite standard.

The research reports and the results presented in this thesis have not been submitted in parts or in full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Building Sustainability accounts for Energy use (Embodied, operational, others) with associated Greenhouse gas emissions, waste generation, total usage of construction materials, materials Recycling, water use etc. in buildings and is directly responsible for building performance for design or service period. Building envelope plays major role in building embodied and operational energy and resulting emissions associated with production of building materials and building components comprising the same. An analysis for building sustainability performance based on building envelope is crucial.

A life-cycle based methodology for 'Building Sustainability Performance' with contextual environmental impact obtained through Sustainability Impact Indicators (SII) and building performance through Sustainability Performance Factors (SPF) is developed leading to Sustainable Performance Index (SPI) for buildings. A computer code was written based on above mathematical formulation in MATLAB®. Life cycle period is ascertained as Intended Design Life (IDL) of building for residential buildings. This Life cycle period is modelled as three-stage system block under 'Cradle-Gate-Grave' nexus. Total building life cycle energy (LCE) is divided in this research as embodied and operational energy. Distinction is drawn between direct and indirect energy implication for building sustainability performance and is evaluated and compared using factors i.e. 'λ_i'. These are quantified for transportation, maintenance, waste etc. This leads to increase in overall building life cycle energy by 5-7%. Developed index was

evaluated as (MBH) Model building house with varying floor areas as MBH1 and MBH2. Building parametric was evaluated for SPI sensitivity. A case study was then conducted on seven storeyed mid-rise apartment building in composite climate (New Delhi). The index was then optimized using Genetic Algorithm (GA). A computer code was developed for GA based SPI optimization in MATLAB®. The index was then optimized for three climatic zones in India. A Graphical user SPI interface was also created to calculate and analyse building SPI as SPI (B) and SPI (O) and to conduct building components analysis. Several new terminologies (Thermal Ventilation Factor (β); Ventilation Area Ratio (σ); Penetration Depth Ratio (λ)) as part of building performance under SPF were proposed and integrated in Sustainability Performance Index.

It was found out that 'Direct Energy' contribution to total life cycle energy is less than 5 %. Building Sustainability Performance or SPI value based on LCA with IDL reduces with increase in building floor area. SPI values of MBH2 falls by 5.5% when compared to MBH1. Building Operational Energy dominates for RCC structure based residential buildings in Tropical and semi-Tropical region in total life cycle energy (89-90 %) for IDL as 50 yrs. SPI value is least for Hot and Dry climate in India i.e. 7.73 (MBH2). SPI values i.e. SPI (O) increase by 27.36 % over SPI (B) for MBH1 in composite climate. SPI values i.e. SPI (O) increase by 28.85 % over SPI (B) for MBH2 in composite climate.

SPI could be used as computer decision tool for analysis and comparison of designed residential buildings. Same can be utilized for existing buildings for building operational characteristics for working Reference Energy use Intensities after using optimization of SPI. SPI index could be utilized for comparing buildings in different climate zones of India. SPI will aid in reducing embodied energy as well as total building life cycle energy. Same tool could be utilized for comparing building components in different regions. SPI could be utilized as tool during design and planning stage to compare and pool building prototypes for building 'Sustainability Performance' under Integrated Design Process for buildings. It could be used as decision and analytical tool for Designers, Planners and in Policy Making.

सार

संबद्ध ग्रीनहाउस गैस उत्सर्जन, अपशिष्ट उत्पादन, निर्माण सामग्री के कुल उपयोग, सामग्रियों के पुनर्चक्रण, जल के उपयोग आदि के साथ भवनों में ऊर्जा के उपयोग (सन्निहित, संचालन, अन्य) के लिए स्थायित्व खाते का निर्माण और डिजाइन या सेवा अवधि के लिए प्रदर्शन के निर्माण के लिए सीधे जिम्मेदार है। बिल्डिंग लिफ़ाफ़े सन्निहित और परिचालन ऊर्जा के निर्माण में प्रमुख भूमिका निभाता है और परिणामस्वरूप उत्सर्जन में निर्माण सामग्री और भवन घटकों के उत्पादन से जुड़े होते हैं। भवन लिफाफे के आधार पर स्थिरता प्रदर्शन के निर्माण के लिए एक विश्लेषण महत्वपूर्ण है।

Act सस्टेनेबिलिटी इंपैक्ट इंडिकेटर्स (SII) के माध्यम से प्राप्त प्रासंगिक पर्यावरणीय प्रभाव के साथ S बिल्डिंग सस्टेनेबिलिटी परफॉर्मेंस 'के लिए जीवन-चक्र आधारित कार्यप्रणाली और इमारतों के लिए सस्टेनेबिलिटी परफॉर्मेंस फैक्टर्स (SPI) के माध्यम से बिल्डिंग परफॉर्मेंस का विकास किया जाता है। MATLAB® में गणितीय सूत्रीकरण के आधार पर एक कंप्यूटर कोड लिखा गया था। आवासीय भवनों के लिए जीवन चक्र की अवधि का इरादा डिजाइन जीवन (IDL) के रूप में किया जाता है। यह जीवन चक्र अवधि-क्रैडल-गेट-ग्रेव 'नेक्सस के तहत तीन-चरण प्रणाली ब्लॉक के रूप में तैयार की गई है। कुल निर्माण जीवन चक्र ऊर्जा (LCE) इस अनुसंधान में सन्निहित और परिचालन ऊर्जा के रूप में विभाजित है। स्थायित्व प्रदर्शन के निर्माण के लिए प्रत्यक्ष और अप्रत्यक्ष ऊर्जा निहितार्थ के बीच अंतर निकाला जाता है और इसका मूल्यांकन कारकों की तुलना में अर्थात्। Λi 'के साथ किया जाता है। इन्हें परिवहन, रखरखाव, अपशिष्ट आदि के लिए निर्धारित किया जाता है। इससे समग्र भवन जीवन चक्र ऊर्जा 5-7% तक बढ़ जाती है। विकसित सूचकांक का मूल्यांकन MBH1 और MBH2 के रूप में अलग-अलग मंजिल क्षेत्रों के साथ (MBH) मॉडल बिल्डिंग हाउस के रूप में किया गया था। एसपीआई संवेदनशीलता के लिए बिल्डिंग पैरामीट्रिक का मूल्यांकन किया गया था। तब समग्र जलवायु (नई दिल्ली) में सात मंजिला मध्य-उदय अपार्टमेंट इमारत पर एक केस अध्ययन किया गया था। सूचकांक को फिर जेनेटिक एल्गोरिथम (जीए) का उपयोग करके अनुकूलित किया गया था। MATLAB® में GA आधारित SPI अनुकूलन के लिए एक कंप्यूटर कोड विकसित किया गया था। तब भारत में तीन जलवायु क्षेत्रों के लिए सूचकांक को अनुकूलित किया गया था। एसपीआई (बी) और एसपीआई (ओ) के रूप में एसपीआई के निर्माण और विश्लेषण और भवन घटकों के विश्लेषण का संचालन करने के लिए एक ग्राफिकल यूजर एसपीआई इंटरफ़ेस भी बनाया गया था। एसपीएफ़ के तहत निर्माण प्रदर्शन के हिस्से के रूप में कई नई शब्दावली (थर्मल वेंटिलेशन फैक्टर (;); वेंटिलेशन एरिया रेश्यो (ologies); पेनेट्रेशन डेप्थ रेशियो (λ)) प्रस्तावित किया गया था और इसे स्थिरता प्रदर्शन सूचकांक में प्रस्तावित किया गया था।

यह पता चला कि जीवन चक्र की कुल ऊर्जा में 'प्रत्यक्ष ऊर्जा का योगदान 5% से कम है। बिल्डिंग फ्लोर एरिया में वृद्धि के साथ आईडीसी के साथ एलसीए पर आधारित सस्टेनेबिलिटी परफॉर्मेंस या एसपीआई वैल्यू का निर्माण। MBH1 की तुलना में MBH2 का SPI मान 5.5% तक गिर जाता है। बिल्डिंग ऑपरेशनल एनर्जी 50

साल के लिए आईडीएल के लिए कुल जीवन चक्र ऊर्जा (89-90%) में उष्णकटिबंधीय और अर्ध-उष्णकटिबंधीय क्षेत्र में आरसीसी संरचना आधारित आवासीय भवनों के लिए हावी है। भारत में गर्म और शुष्क जलवायु के लिए SPI का मूल्य कम से कम है यानी 7.73 (MBH2)। एसपीआई मान यानी एसपीआई (ओ) मिश्रित जलवायु में एमबीएच 1 के लिए एसपीआई (बी) पर 27.36% की वृद्धि। मिश्रित जलवायु में SPH (B) के SPI (B) पर SPI का मान यानी SPI (O) 28.85% बढ़ जाता है।

एसपीआई को डिजाइन किए गए आवासीय भवनों के विश्लेषण और तुलना के लिए कंप्यूटर निर्णय उपकरण के रूप में इस्तेमाल किया जा सकता है। एसपीआई के अनुकूलन का उपयोग करने के बाद काम करने वाले संदर्भ ऊर्जा उपयोग तीव्रता के लिए परिचालन विशेषताओं के निर्माण के लिए मौजूदा इमारतों के लिए समान उपयोग किया जा सकता है। एसपीआई सूचकांक का उपयोग भारत के विभिन्न जलवायु क्षेत्रों में इमारतों की तुलना करने के लिए किया जा सकता है। एसपीआई सन्निहित ऊर्जा को कम करने के साथ-साथ कुल निर्माण जीवन चक्र ऊर्जा में सहायता करेगा। विभिन्न क्षेत्रों में भवन घटकों की तुलना के लिए एक ही उपकरण का उपयोग किया जा सकता है। एसपीआई को भवनों के लिए एकीकृत डिजाइन प्रक्रिया के तहत ability सस्टेनेबिलिटी प्रदर्शन ’के निर्माण के लिए प्रोटोटाइप की तुलना और पूल निर्माण के लिए डिजाइन और योजना चरण के दौरान उपकरण के रूप में उपयोग किया जा सकता है। यह डिजाइनर, प्लानर्स और पॉलिसी मेकिंग के लिए निर्णय और विश्लेषणात्मक उपकरण के रूप में इस्तेमाल किया जा सकता है।

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NOMENCLATURE

SYMBOL	DESCRIPTION
A	Area of component [m^2]
I	Solar Intensity [W/ m^2]
U	Overall Thermal Transmittance [W/ (m^2. ^oC)]
C_v	Ventilation Coefficient [W/ ^oC]
f_s	Light Correction Factor
h	Height [m]
k	Flow or normal coefficient
m	Quantity of 'i^{th}' material [Kg]; maintenance ; mean
n	Intended Design Life Period [yrs.]
r_i	Sustainability Resiliency Ratio
w_o	Building Critical Dimension [m]
α	Absorptivity of material
β	Thermal Ventilation Factor [m^2/s^2]
σ	Ventilation Area Ratio
ψ	Sustainability Impact Indicators

φ	Sustainability Performance Factors
θ	Solar gain factor
λ'_s	Sustainability Referential Factors
λ_p	Penetration Depth Ratio (PDR)

LIST OF ABBREVATIONS

IDL	Intended Design Life
LCA	Life Cycle Analysis
LCE	Life Cycle Energy
LCF	Light Correction Factor
MBH	Model Building House
PDR	Penetration Depth Ratio
SII	Sustainability Impact Indicator
SIF	Sustainability Impact Function
SPI	Sustainability Performance Index
SPF	Sustainability Performance Function
SRQ	Sustainability Relativity Quotient
TVF	Thermal Ventilation Factor
VAR	Ventilation Area Ratio