

A Model for Developing Retrofitting Strategies for Office Buildings

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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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List of Abbreviations

ABCB	Australia Building Codes Board
AC	Alternating current
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
ASGB	Assessment Standard of Green Building
ASHRAE	American Society of Heating Refrigerating and Air-Conditioning Engineers
BCR	Benefit/cost ratio
BEES	Building for Environmental and Economic Sustainability
BEEEX	Building Energy Exchange
BIM	Building Information Modelling
BMCS	Building management control system
BMS	Building management system
BREEAM	Building Research Establishment Environmental Assessment Method
BSI	British Standards Institution
CBA	Cost benefit analysis
CFD	Computation fluid dynamics
CIB	International Council for Research and Innovation in Building and Construction
DC	Direct current
EAC	Equivalent annual cost
EC	Embodied carbon
ECBA	Environmental cost benefit analysis
EE	Embodied energy
eGRID	Emission & Generation Resource Integrated Database
ELCA	Environmental life cycle assessment
ELCC	Environmental life cycle costing

EPA	Environmental Protection Authority (U.S.)
EPD	Environmental product declarations
FU	Functional unit
GBRS	Green building rating system
GHG	Greenhouse gases
GP	Goal programming
HMD	Head-mounted display
HVAC	Heating, ventilation and air conditioning
I-O	Input-Output
ICE	Inventory of Carbon and Energy
IEA	International Energy Agency
IEQ	Indoor environmental quality
IESNA	Illuminating Engineering Society of North America
IRR	Internal rate of return
IVS	Immersive virtual simulation
LCA	Life cycle assessment
LCC	Life cycle costing
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LCSA	Life cycle sustainability assessment
LDPE	Low density polyethylene
LEED	Leadership in Energy and Environmental Design
MADM	Multi-attribute decision making
MCDM	Multi-criteria decision making
MLOP	Multiple linear objective programming
MNLOP	Multiple nonlinear objective programming
MODM	Multi-objective decision making

MOHURD	Ministry of Housing and Urban-Rural Development of the People’s Republic of China
MRL	Machine-room-less technology
NCC	National Construction Code
NIST	National Institute of Standards and Technology (US)
NPV	Net present value
OAT	One-At-a-Time
PBP	Payback period
PMV	Predicted mean vote
PP	Semi-crystalline polypropylene
PRPs	Performance reference points
PV	Photovoltaic
RSP	Reference study period
SDSN	Sustainable Development Solutions Network
SETAC	Society of Environmental Toxicology and Chemistry
S-LCA	Social life cycle assessment
SLCA	Social cost benefit analysis
SHGC	Solar heat gain coefficient
SOTNBS	Survey Office of The National Bureau of Statistics in Zhejiang
TBL	Triple-bottom line
UN	United Nations
UNEP	United Nations Environment Programme
VAT	Value Added Tax
VAV	Variable air volume
WCED	World Commission on Environment and Development
WLC	Weighted linear combination
WWR	Window/wall ratio
ZPBS	Zhejiang Provincial Bureau of Statistics

Abstract

A considerable amount of material, water, energy and other natural resources are invested in the building sector. The poor performance in energy efficiency of most existing buildings and the relatively low rate of new and more efficient construction means that it will be a long time before new buildings with better performance can replace existing poor building stock. Compared to demolition and construction of new buildings, retrofitting of existing buildings may be a faster method to modernise the existing stock and mitigate unfavourable impacts on the natural environment from the building sector. However, most existing sustainability assessment methods and decision-making frameworks focus on the environmental and economic performance of buildings without much consideration of the social dimension. While retrofitting may be the best chance for existing buildings to achieve sustainability, it is necessary to consider all three sustainability dimensions when retrofitting existing buildings to achieve economic growth, protect the natural environment, and increase social wellbeing.

This study develops a model for deciding retrofitting strategies for office buildings to improve their sustainability performance. Different with most other existing decision-making models for retrofitting strategies which only consider the environmental and economic dimensions, the model developed in this study integrates all the environmental, economic and social dimensions into the decision-making process of retrofitting strategies. The retrofitting strategies developed by the model can maximise improvement of existing buildings in these three dimensions within project constraints and meet retrofitting goals at the same time. This is realised via a process from conceptualisation to operationalisation. First, a conceptual model for deciding retrofitting strategies for office buildings from a triple-bottom line perspective is developed based on literature review. Then, the conceptual model is converted to an operating model to suit local situations for sustainable retrofitting. A survey and focus group discussions are conducted to collect opinions about locally suitable retrofitting activities and assessment criteria from professionals in the construction and property management sectors as well as the key stakeholders of retrofitting. Finally, a case study is conducted in which the operating model is used to develop retrofitting strategies for the case building. With suitable potential retrofitting strategies developed for the case building, the validity of the conceptual model is verified. Meanwhile, the case study illustrates the process of quantifying and using the conceptual model to develop retrofitting strategies for an office building.