AN INVESTIGATION OF THE IMPACT OF CLIMATE CHANGE ON ENERGY USE IN BUILDINGS IN DIFFERENT CLIMATE ZONES ACROSS CHINA

WAN KOK WING

DOCTOR OF PHILOSOPHY

CITY UNIVERSITY OF HONG KONG

JULY 2011

ABSTRACT

Recent reports by the Inter-governmental Panel on Climate Change (IPCC) have raised public concerns about energy use and the environmental implications. Buildings, energy and the environment are key issues facing the building professions and energy policy makers worldwide. The increases in the global temperatures exert pressure on building energy end-uses and have an impact on human being and the environment. The objective of this study is to investigate impact of climate change on the built environment in terms of human comfort and building energy consumption and mitigate the projected increase of energy use and carbon emissions in different climates across China.

The scientific basis of climate change was outlined. It is generally acknowledged that the drivers of climate change were due mainly to the anthropogenic activities in raising the atmospheric concentrations of CO_2, CH_4 and N_2O. A total of five cities in China - Harbin, Beijing, Shanghai, Kunming and Hong Kong were selected to represent the five major architectural climate zones: severe cold, cold, hot summer and cold winter, mild and hot summer and warm winter. Historical and future conditions of five climatic variables (minimum, maximum and mean dry-bulb temperatures, humidity and global solar radiation) during 1901-2100 were obtained from the CRU TS 2.1 data set and the WCRP CMIP3 multi-model database for two emission scenarios (low and medium forcing).

Underlying trends of long-term summer and winter discomfort in terms of heat and cold stresses in different climate zones across China in the 20^{th} (1901-2002) and 21^{st} (2003-2100) centuries were investigated. A gradual shift from predominantly negative to positive comfort index was observed as one moved across the climate zones from the north to warmer climates in the south. For the severe cold and cold regions in the north, reductions in cumulative cold stress outweighed the increase in cumulative heat stress resulting in an overall decreasing trend in the annual cumulative stress, and vice versa for the other three warmer climate zones in the south. A reduction in cold stress would result in less winter heating and an increase in heat stress more cooling requirement.

Principal component analysis of dry-bulb temperature, wet-bulb temperature and global solar radiation was considered to determine a new climatic index (principal component Z). Multi-year building energy simulations were conducted for five generic office buildings in Harbin, Beijing, Shanghai, Kunming and Hong Kong in different climatic zones in China. Regression models were developed to correlate the simulated monthly heating, cooling and total building energy use with the corresponding Z. The coefficient of determination (R^2) varied between 0.77 and 0.99, indicating reasonably strong correlation. Future trends of heating and cooling energy consumption as well as total building energy use for the two scenarios (i.e. low and medium forcing) during 2001-2100 (2009-2100 for Hong Kong) were determined. A decreasing trend of energy use for heating and an increasing trend of energy for cooling due to climate change in future years were observed. For low forcing, the estimated reduction in heating was 22.3% in Harbin, 26.6% in Beijing, 55.7% in Shanghai, 13.8% in Kunming and 23.6% in Hong Kong; the increase in cooling energy 18.5% in Harbin, 20.4% in Beijing, 11.4% in Shanghai, 24.2% in Kunming and 14.1% in Hong Kong; and the overall impact on total building use -4.2% in Harbin, 0.8% in Beijing, 0.7% in Shanghai, 4.1% in Kunming and 4.3% in Hong Kong.

Energy-efficient measures were considered to mitigate the impact of climate change on building energy use. Seven design variables that could have significant energy saving and CO_2 reduction potentials were selected: wall U-value, window U-value, shading coefficient, window-to-wall ratio, summer set point temperature, lighting load density and chiller coefficient of performance. Raising the summer set point temperature by 1-2^oC and lowering the lighting load density by 2 W/m^2 could have great mitigation potential. It was found that there would be an overall increase in carbon emissions in all five cities, ranging from 0.5% in Harbin to 4.3% in Hong Kong for low forcing. There would be substantial reduction in the annual average carbon emissions in the 21st century if the cleaner fuel mix projected in 2020 was adopted: ranging from 4368 tCO_2e to 2221 tCO_2e in Hong Kong and from 6670 tCO_2e to 4195 tCO_2e in Beijing. These would represent about 37% reduction on the mainland and 49% in the Hong Kong SAR. Although this study was conducted for the five major architectural climates across China, it is envisaged that the approach could be applied to other locations with similar or different climates. Given the growing concerns about climate change and its likely impact on the built environment, this could have important energy and environmental implications.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

A1	emissions scenario
A1B	emissions scenario (subgroup of A1)
A1FI	emissions scenario (subgroup of A1)
A1T	emissions scenario (subgroup of A1)
A2	emissions scenario
ACH	air change per hour
ACS	annual cumulative stress
AGCMs	atmospheric general circulation models
AHU	air-handling unit
AOGCMs	atmosphere-ocean coupled general circulation model
APR	annual physioclimatic regime
AR1	IPCC first assessment report
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ATCM	average temperatures of the coldest month
ATHM	average temperatures of the hottest month
B1	emissions scenario
B2	emissions scenario
BCCR-BCM2.0	general circulation model (Norway)
BDL	building description language
BLAST	Building Load Analysis & System Thermodynamics
C	cold climate zone

C++	C++ computer programming language
CABR	China Academy of Building Research (China)
CCS	cumulative cold stress
CDDs	cooling degree days
CDF	cumulative distribution function
CHS	cumulative heat stress
CLP	China Light & Power Company
COP	chiller coefficient of performance
CRT	cathode ray tube
CRU	Climate Research Unit (UK)
CSEP	China Sustainable Energy Program
CVRMSE	coefficient of variation of the root mean square error
CWEC	Canadian weather for energy calculations
DBT	dry-bulb temperature
DDC	data distribution centre
DECC	Department of Energy & Climate Change (UK)
DEFRA	Department for Environment Food and Rural Affairs (UK)
DOE-2	DOE-2 building energy simulation program
DOEWTH	DOE-2 weather data processor
DPT	dew-point temperature
DRY	design reference year
DSY	design summer year
DTI	daytime index
EEM	energy efficiency measure
EERE	Energy Efficiency & Renewable Energy
EIA	Energy Information Administration (US)
EMSD	Electrical and mechanical Services Department (HKSAR)
EnergyPlus	EnergyPlus building energy simulation program
eQuest	eQuest building energy simulation program

ERW	Environmental Research Web (UK)
ESP-r	Environmental Systems Performance, version r
EU	European Union
FORTRAN	FORTRAN computer programming language
GCMs	general circulation models
GDP	gross domestic product
GFA	gross floor area
GHGs	greenhouse gases
GISS-AOM	general circulation model (USA)
GPCC	Global Precipitation Climatology Centre
GSR	global solar radiation
HDDs	heating degree days
HSCW	hot summer and cold winter climate zone
HSWW	hot summer and warm winter climate zone
HVAC	heating, ventilation and air conditioning
IEA	International Energy Agency (USA)
IEO	International Energy Outlook (USA)
INM-CM3.0	general circulation model (Russia)
IPCC	Inter-governmental Panel on Climate Change
IWEC	international weather for energy calculation
JJH	James J. Hirsch & Associates
LBNL	Lawrence Berkeley National Laboratory (formerly LBL)
LCD	liquid crystal display
LED	light-emitting diode
LLD	lighting load density
M	mild climate zone
MBE	mean bias error
MIROC3.2H	general circulation model (Japan)
NBR	National Business Review

NCAR-CCSM3.0	general circulation model (USA)
NCDC	National Climate Data Centre (formerly NCC)
NDRC	National Development and Reform Commission
NetCDF	network common data form
NMA	National Meteorological Agencies
NMBE	normalised mean bias error
NTI	night-time index
NWP	numerical weather prediction
OECD	Organisation for Economic Co-operation and Development
OGCMs	oceanic general circulation models
OTTV	overall thermal transfer value
PCA	principle component analysis
PCMDI	program for climate model diagnosis and intercomparison
PCS	proportional cumulative stress
PER	primary energy requirement
PET	physiological equivalent temperature
PMV	predicted mean vote
PPD	percentage of dissatisfied
RH	relative humidity
RMSE	root mean square error
SAR	IPCC Second Assessment Report
SC	severe cold climate zone
SC	shading coefficient
SPM	summary for policymakers
SRES	special report of emissions scenarios
SST	summer set point temperature
TAR	IPCC Third Assessment Report
TMMs	typical meteorological months
TMY	typical meteorological year

TMY2	typical meteorological year 2
TRNSYS	TRaNsient SYstem Simulation Program
TRY	test reference year
TSU	technical support units
UKCIP	UK Climate Impacts Programme
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USDOE	US Department of Energy's Office of Energy
VAV	variable air volume
VisualDOE	VisualDOE building energy simulation program
WBT	wet-bulb temperature
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WSP	wind speed
WWR	window-to-wall ratio