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Energy consumption and CO_2 emission responsibilities of terminal buildings: A case study for the future Istanbul International Airport

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ABSTRACT

Airport terminal buildings are used to be treated as stand-alone buildings for their energy performance. Previous studies in the literature fall short of recognizing functional and physical relations of terminal buildings with landside and airside airport operations. In order to avoid these shortcomings, this paper extends the terminal building energy performance analysis to a broader context and expands the analysis envelope to expose the true impact of a terminal building on energy consumption and the combined emissions that it is responsible for. In this respect, this study investigates whether a green terminal building in a new airport planned for the city of Istanbul with an annual 150 million passenger capacity may off-set the loss of CO_2 sequestration potential from cutting at least 657000 trees for the airport construction or not. Additional CO_2 emissions corresponding to the estimated longer approach and climb out flights due to the unfavorable site selection have also been considered. This article compares a business as usual type of terminal building with four green terminal building scenarios having different CO_2 emission reduction potentials. The first-law and the second-law analysis of thermodynamics have shown that constructing a green terminal building complex may not offset its CO_2 emissions responsibility unless a very intensive re-forestation activity is implemented and the site is properly re-selected. As a result, this study has exemplified the essential boundaries for energy consumption analysis envelope for an airport terminal building and its true emissions responsibility.

1. Introduction

The most important function of a terminal building is to facilitate a link between "landside" and "airside", and as such is interlinked to all other functions of the airport. As a result, the terminal building causes additional energy consumption due to the nature of its function. Therefore, an analysis of the terminal building alone would not be capable of expressing its true impact on the environment since it is due to the existence of this building that all other airport operations take place. Yet, previous papers, including the ones published in Energy and Building, have limited their energy performance analysis to the terminal building itself. For example, Zomer et al. [1] have analyzed the energy performance compromises of building-integrated and building-applied photovoltaic systems in Brazilian Airports. They have limited their study to the terminal building only. Furthermore, they did not take into account that photo-voltaic panel applications in airports and airport buildings may be severely limited by the regulations of FAA (Federal Aviation Administration) due to aircraft safety and pilot's visibility. This example alone justifies the need that an airport building must take into account the airside factors. Mardaljevic [2] analyzed the isolated impact of solar shading on energy performance at the roof Changi airport terminal building in China. Fan et al. [3] have developed a simulation model for an airport HVAC system and tried to optimize the HVAC control system with the objective of reducing the energy consumption. CO_2 emissions and other impacts of the terminal building were indirectly addressed in their paper. Balaras et al. [4] have focused on various energy savings measures and indoor environmental quality in Hellenic Airports. Somcharoenwattana et al. [5] have extended their analysis to the CO_2 emissions impact of the Suvarnabhumi airport in Thailand after introducing a cogeneration plant and their paper has successfully hinted out that an airport terminal building must be analyzed for its performance from a wider perspective beyond the building itself.

This paper aims to bring the performance analysis of the airport terminal buildings to a broader context in order to understand the true impact of terminal buildings to the built environment. In this respect, a detailed analysis algorithm was developed and applied to the new airport with a planned 150 million passengers per annum (ppa) in Istanbul, which is expected to break ground in 2014. This

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Nomenclature

AP	Annual passenger handling capacity of the airport in its first phase of operation (100×10^6), ppa
B	Base load factor, dimensionless
c_i	Unit CO_2 content of the fuel used for power and heat generation within the airport boundaries, kg CO_2/kWh
c_j	Unit CO_2 content of the fuel used for power and heat generation taking place outside the airport boundaries, kg CO_2/kWh
CF	Natural survival rate factor, dimensionless
$CHPH\eta$	Partial heat generation efficiency of combined heat and power system (CHP), dimensionless
$CHPE\eta$	Partial power generation efficiency of CHP system, dimensionless
D	Diversity factor, dimensionless
DF	Number of trees to be subjected to cutting (deforestation), dimensionless
E	Electrical energy demand, kWh
E_a	Annual electrical energy Demand, kWh
ES_a	Energy savings per annum according to PES_{RCHP}, kWh/annum
E_p	Peak electrical energy demand (sum of label power values of all equipment and lighting), kWh
FS	Annual additional fuel spending that the site selection of the airport is responsible, L/annum
f	Jet fuel spent for each passenger seat-mile, L/seat-mile
h	Daily airport operating hours, h
LCS	Loss of CO_2 sequestration potential due to deforestation, ton CO_2/annum
m	Annual full operating days of the airport (considering adverse meteorological and other conditions like strike, natural disasters, security reasons etc), days/annum
N	Number of trees to be planted for re-forestation purposes
n	Annual-averaged heat to electrical energy demand ratio, dimensionless
OR	Annual average passenger seat occupancy ratio of aircraft using the airport, dimensionless
PES	Primary energy savings ratio, per-cent
PES_{RCHP}	Rational Exergy Management Efficiency embedded *PES*, per-cent
Q	Heat demand, kWh
$RefH\eta$	Reference value for the partial heat generation efficiency by CHP, dimensionless
$RefE\eta$	Reference value for the partial power generation efficiency by CHP, dimensionless
$Ref\psi_{RCHP}$	Reference value for the rational exergy management efficiency of the CHP system, 0,2024 [5], dimensionless
S	Additional CO_2 emissions responsibility of the airport due to unfavorable site selection, ton CO_2/annum
s	Annual Carbon sequestration potential of a tree per annum, kg carbon/annum (multiply by 3,67 in order to convert to kg CO_2/annum.
T_{app}	Application temperature, K
T_a	Design comfort air temperature in a building, K
TCO_2	Total CO_2 emissions responsibility, $LCS + \sum CO_2 + S$, ton CO_2/annum
T_f	Combustion (or equivalent) temperature of exergy source (fuel), K
T_g	Annual-averaged ground temperature at approximately 1,5 m, K
T_{ref}	Reference environment temperature, K
x	Oxidation fraction of jet fuel, dimensionless
X	CO_2 sequestration ratio, dimensionless

Greek Symbols

η_{Bi}	On-site boiler efficiency, first-law, dimensionless
η_{pj}	Remote power plant efficiency, first-law, dimensionless
η_T	Power transmission efficiency, dimensionless
ψ_{Ri}	Rational Exergy Management Efficiency for on-site electromechanical systems
$\sum CO_2$	Combined CO_2 emission responsibility of the terminal building complex, ton CO_2/annum
ΔCO_2	CO_2 sequestration potential, ton CO_2/annum
δ_{cd}	Additional flight distance due to unfavorable site selection (approach or climb out)

Abbreviations

ABSC	Absorption cooling machine
AC	Air conditioning
ADSC	Adsorption cooling machine
BAU	Business as usual
CHP	Combined Heat and Power
CWT	Cold water storage tank
EASA	European Aviation Safety Agency
EEA	European Environment Agency
EU	European Union
FAA	Federal Aviation Administration
GSHP	Ground-source heat pump
HE	Heat exchanger
HWT	Hot-water storage tank
L	liter (metric unit)
NZEB	Net-zero energy and net-zero exergy building
nZEB	Nearly-zero energy building (According to REHVA)
ppa	Passenger per annum
PV	Photo-voltaic
PVT	Photo-voltaic-thermal
PVTC	Photo-voltaic-thermal-cold
REHVA	Federation of European Heating, Ventilation and Air Conditioning Associations
UDHB	Republic of Turkey Ministry of Transport, Maritime Affairs, and Communications

Subscripts

BS	Base scenario (BAU scenario)
cd	Cruising distance, nautical miles
G	Green
i	Within airport boundaries (on-site)
j	Off-site locations

will be the third international airport for Istanbul. Among several environmental, safety, and air traffic concerns, the selected site of the airport, which is nearby a dense forest requires cutting of at least 657000 trees. In order to off-set the corresponding CO_2 sequestration loss from this activity, it has been claimed that the terminal building complex is going to be designed and constructed with a green airport concept in mind. In this study, leaving all other dimensions of environmental concerns aside, the annual CO_2 sequestration potential of the green airport terminal is weighted