Technical and Economic Assessment of Medium Sized Solar-Assisted Air-Conditioning in Brazil

DISSERTAÇÃO DE MESTRADO

Dissertation presented to the Postgraduate Program in Urban and Environmental Engineering of the Departamento de Engenharia Civil, PUC-Rio as partial fulfillment of the requirements for the degree of Mestre m Engenharia Urbana e Ambiental (opção Profissional).

Advisor: Prof. Celso Romanel
Co-Advisor: Profa. Elizabeth Duarte Pereira

Rio de Janeiro
January 2010
Till Felix Reichardt

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Prof. Celso Romanel
Orientador, PUC-Rio

Profa. Elizabeth Duarte Pereira
Co-Orientadora, Grupo Anima de Educação

Dr. Johannes Kissel
GTZ-Brasil

Dr. Marcos Alexandre Teixeira
GTZ-Brasil

Prof. Alcir de Faro Orlando
Departamento de Engenharia Mecânica, PUC-Rio

Prof. José Eugénio Leal
Coordenador Setorial do Centro Técnico Científico, PUC-Rio

Rio de Janeiro, 25/01/2010
Till Felix Reichardt

Graduated in Environmental and Production Engineering from Technical University of Heilbronn, Germany, in 2006. Worked as a design engineer for the company Bartec Benke GmbH (Hamburg, Germany) during two years.

Bibliographic data

Reichardt, Till Felix


135 f.: il. 29,7 cm


Bibliographic references included.

Ever bigger machines, entailing ever bigger concentrations of economic power and exerting ever greater violence against the environment, do not represent progress: they are a denial of wisdom. Wisdom demands a new orientation of science and technology towards the organic, the gentle, the non-violent, the elegant and beautiful.

E. F. Schumacher

Small Is Beautiful: a study of economics as if people mattered
Acknowledgments

The author would like to thank Prof. Celso Romanel and Profa. Elizabeth Duarte Pereira for their guidance and support, anyone at DAAD (especially Karin Führ) for financial support during my master’s degree program in Rio de Janeiro, Brazil.

Special thank to the GTZ team in Rio de Janeiro, especially to Dr. Johannes Kissel, Dr. Marcos Teixeira and Andreas Nieters for their inspiration, discussion, support and information.

Very grateful I am also for the collaboration with PROCEL, especially with Andre Cleiman and Luciana Lopes Batista.

Katrin Spiegel (SolarNext), Ralf Kynast (Solvis), Bud Leavell (Yazaki), Christian Zahler (Mirroxx), Luiz Alexandre Alves (Cumulus), Alexandre Lopes (Benco) and Gabriel Neumeyer (Schüco) thanks for answering immediately a lot of essential technical questions.

Finally, I would like to thank Robert Mack (engineering consultant) for an excellent introduction in thermal building simulation and information about air-conditioning and solar collectors.

Last but not least I would like to thank my family and Mariana Sales Fernandez Dominguez for their support.
Resumo


No Brasil, devido ao clima tropical, muita energia elétrica é utilizada em sistemas de ar condicionado. Devido à excelente irradiação solar que incide na maior parte do país, existem boas condições para atender esta grande demanda de refrigeração através da utilização de sistemas de ar condicionado assistido por energia solar térmica. Nesta dissertação, as mais importantes tecnologias que utilizam a energia solar para a climatização foram verificadas quanto a sua aplicabilidade técnica e econômica no Brasil, com foco em sistemas de médio porte. Os princípios básicos para o dimensionamento de um sistema de refrigeração solar são descritos e um estudo de caso é apresentado e discutido, comparando-se um sistema de ar condicionado assistido por energia solar (auditório em Guaratinguetá, São Paulo) com um sistema tipo split convencional. No estudo deste caso, a dinâmica de simulação térmica de edifícios foi modelada utilizando o programa Helios-PC. Também se analisa como a carga térmica de resfriamento pode ser diminuída considerando-se uma temperatura adequada no interior da edificação, de acordo com as normas brasileiras de conforto térmico, como também pelo emprego de isolamento adequado na construção do edifício.

Palavras - chave
Ar condicionado solar; Coletores solares térmicos; Simulação da carga térmica de resfriamento; Eficiência energética; Estimativa econômica.
Abstract

In Brazil a lot of electrical energy is used by building air-conditioning because of the tropical climate. In many cases there is a general congruence of solar irradiation and demand for building air-conditioning and solar thermal cooling has the potential to satisfy a part of the rapidly growing cooling demand. Due to excellent solar irradiance and a high cooling demand there exists in Brazil good conditions for the use of solar-assisted air-conditioning. In this work the most important solar cooling techniques and their suitability in Brazil are discussed. The objective of the present study is to analyze the technical and economic feasibility of medium sized solar-assisted air-conditioning in Brazil. The energy saving potential of solar-thermal air-conditioning in comparison to best practical solutions in Brazil using conventional split air-conditioning systems, is shown based on a case study (auditorium in Guaratinguetá - São Paulo). The economy of solar-assisted air-conditioning is thereby discussed. The basic principles for the dimensioning of a system for solar cooling are described. The auditorium in the case study is modelled by using the dynamic thermal building simulation program Helios-PC. In this context it is, as well, demonstrated how the cooling load could be decreased by adapting the indoor temperature according to the Brazilian standards of thermal comfort and by using building insulation.

Keywords
Solar cooling air-conditioning; Solar thermal collectors; Dynamic thermal building simulation; Energy efficiency; Economic assessment.
Zusammenfassung


Schlüsselwörter

Solares Kühlen; Klimaanlage; Solarkollektoren; Dynamische Gebäudesimulation; Kühllast; Energieeffizienz; Wirtschaftlichkeitsberechnung.
## Contents

1 Introduction 18

1.1. Objective 25

2 Technical overview of active techniques 26

2.1. Technologies applicable for solar-assisted air-conditioning 26

2.1.1. Chilled water systems 33

2.1.1.1. Absorption Chillers 34

2.1.1.2. Adsorption Chillers 40

2.1.1.3. Heat Rejection 44

2.1.2. Open cycle Processes 46

2.1.3. Solar thermal collector 50

2.2. Non- thermally driven application 55

2.2.1. Conventional Electricity driven vapour compression chiller 55

2.2.2. Photovoltaic driven compression cycle 57

3 Case Study 62

3.1. Background Information 63

3.1.1. Location and climate conditions 65

3.2. Simulation and Design 68

3.2.1. The thermal Load of the Building 68

3.2.1.1. Simulation Building Data 69

3.2.1.2. Results of the Simulation 74

3.2.1.2.1. Conclusion 77

3.2.2. Selection and Design of the equipment 79

3.2.2.1. The Cold Production Sub-System 80

3.2.2.2. The load sub-system – air-conditioning equipment 83

3.2.2.3. Heat production sub-system 87

3.2.2.3.1. Thermal solar collector comparison 87

3.2.2.3.2. Back-up and hot water storage 91

3.2.2.3.2.1. Electrically driven compression chiller back-up 92
List of figures

Figure 1.1 - Okura Act City Hotel in Hamamatsu, Japan 19
Figure 1.2 - Megacities of the tropical Belt 20
Figure 1.3 - Applied electrically driven compression Air-Conditioning 21
Figure 1.4 - World market sales rate in 2008 of split air-conditioners 22
Figure 2.1 - General Scheme of the thermally driven cooling process 27
Figure 2.2 - Closed cycle system 28
Figure 2.3 - Open sorption cycle 29
Figure 2.4 - Thermodynamic principle of thermally driven cooling 29
Figure 2.5 - Theoretic limit of solar thermal driven cooling processes 31
Figure 2.6 - Example manufacturer Data 32
Figure 2.7 - Exemplary curves of the coefficient of performance COP 32
Figure 2.8 - Schematic drawing of an absorption chiller 34
Figure 2.9 - Vapour pressure as a function of vapour temperature 35
Figure 2.10 - Detail function scheme of a single-effect Absorption chiller 36
Figure 2.11 - Typical capacity range of a absorption chillers 37
Figure 2.12 - Global solar radiation map of Brazil 38
Figure 2.13 - Examples of concentration solar thermal collectors 39
Figure 2.14 - Two examples of absorption chiller 40
Figure 2.15 - Scheme of an adsorption chiller 41
Figure 2.16 - Two Examples of adsorption chillers 41
Figure 2.17 - Available adsorption chillers 43
Figure 2.18 - Example on the demand for heat rejection 44
Figure 2.19 - Typical scheme of an open wet cooling tower 45
Figure 2.20 - Scheme of a solar thermally driven solid DEC system 46
Figure 2.21 - Relative humidity of the air in relation to the max. Temp. 49
Figure 2.23 - Examples for different construction principles 51
Figure 3.22 - Snapshot of generic spreadsheet 97
Figure 3.23 - Predicted correlation between cooling demand/yield 97
Figure 3.24 - Predicted correlation between cooling demand/yield 98
Figure 3.25 - Predicted correlation between cooling demand/yield 98
Figure 3.26 - Predicted daily demand and available yield (spring) 99
Figure 3.27 - Predicted daily demand and available yield (summer) 99
Figure 3.28 - Predicted daily demand and available yield (autumn) 100
Figure 3.29 - Predicted daily demand and available yield (winter) 100
Figure 3.30 - Predicted total monthly cooling demand and yield (Brazil) 101
Figure 3.31 - Predicted monthly demand and yield (UK) 102
Figure 3.31 - Schematic diagram of the simulated solar cooling syst. 103
Figure 3.32 - Example of an Solar-Assisted Air-conditioning application 103
Figure 3.33 - Acquisition and operation cost (Guaratinguetá) 108
Figure 3.34 - Acquisition and operation cost (Minas Gerais) 108
Figure 4.1 - Typical electric driven screw chiller power curve 115
List of tables

Table 2.1 - Cooling Capacity of Absorption- and Adsorption chiller .................................. 42
Table 3.1 - Monthly average climate data of Guaratinguetá ............................................ 66
Table 3.2 - U-values of the auditorium building model ...................................................... 71
Table 3.3 - Internal thermal comfort (PNB-10, Brazil) .................................................... 73
Table 3.4 - Cooling Load results without building insulation ............................................. 74
Table 3.5 - Cooling Load results with building insulation .................................................. 75
Table 3.6 - Technical data of the Yazaki WFC-SC10 Absorption Chiller ......................... 81
Table 3.7 - Cooling water temperatures ............................................................................ 82
Table 3.8 - Specific cooling capacities of different AC systems ........................................ 84
Table 3.9 - Characteristic values and cost of solar collector typologies ......................... 89
Table 3.10 - Acquisition and specific costs ...................................................................... 105
Table 3.11 - Comparison of electricity consumption and operation cost ....................... 106
Table 3.12 - CO2 savings per year ................................................................................... 109
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>area</td>
</tr>
<tr>
<td>$a_1$</td>
<td>heat transfer coefficient</td>
</tr>
<tr>
<td>$a_2$</td>
<td>temperature depending heat transfer coefficient</td>
</tr>
<tr>
<td>$COP_{\text{Sol}}$</td>
<td>solar collector efficiency</td>
</tr>
<tr>
<td>$C_w$</td>
<td>heat capacity of water</td>
</tr>
<tr>
<td>$G$</td>
<td>solar irradiance at collector surface</td>
</tr>
<tr>
<td>$h_{\text{amb}}$</td>
<td>enthalpy ambient air</td>
</tr>
<tr>
<td>$h_{\text{supply}}$</td>
<td>enthalpy air supply</td>
</tr>
<tr>
<td>$m(t)$</td>
<td>water flow</td>
</tr>
<tr>
<td>$m_{\text{supply}}$</td>
<td>mass air flow</td>
</tr>
<tr>
<td>$P_{\text{el}}$</td>
<td>electric power input</td>
</tr>
<tr>
<td>$Q$</td>
<td>cooling capacity</td>
</tr>
<tr>
<td>$Q_{\text{cold}}$</td>
<td>useful cold</td>
</tr>
<tr>
<td>$Q_{\text{drive}}$</td>
<td>driving heat</td>
</tr>
<tr>
<td>$Q_{\text{reg}}$</td>
<td>external regeneration heat</td>
</tr>
<tr>
<td>$t_a$</td>
<td>ambient temperature</td>
</tr>
<tr>
<td>$T_C$</td>
<td>low temperature</td>
</tr>
<tr>
<td>$T_H$</td>
<td>high temperature</td>
</tr>
<tr>
<td>$T_i$</td>
<td>indoor temperature</td>
</tr>
<tr>
<td>$t_m$</td>
<td>average temperature solar collector</td>
</tr>
<tr>
<td>$T_M$</td>
<td>medium temperature</td>
</tr>
<tr>
<td>$\Delta T$</td>
<td>temperature difference</td>
</tr>
<tr>
<td>$\eta$</td>
<td>efficiency factor</td>
</tr>
<tr>
<td>$\eta_0$</td>
<td>optical efficiency solar collector</td>
</tr>
<tr>
<td>$\eta_{\text{coll}}$</td>
<td>efficiency factor solar collector</td>
</tr>
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### List of acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>HVAC</td>
<td>Heating, Ventilating and Air Conditioning</td>
</tr>
<tr>
<td>IR</td>
<td>Infrared Radiation</td>
</tr>
<tr>
<td>Eletrobrás</td>
<td>Brazilian energy company with headquarters in Rio de Janeiro. The company produces and sells electricity. The majority of the share capital is held by the Brazilian government. It is the biggest energy company in Brazil as well as in Latin America.</td>
</tr>
<tr>
<td>PROCEL</td>
<td>Brazilian Energy Saving Program</td>
</tr>
<tr>
<td>UNESP</td>
<td>São Paulo State University</td>
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<tr>
<td>GTZ</td>
<td>German Technical Cooperation. The GTZ GmbH is an international cooperation enterprise for sustainable development with worldwide operations.</td>
</tr>
<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigerating and Air-Conditioning Engineers</td>
</tr>
<tr>
<td>INMETRO</td>
<td>Brazilian Institute of Metrology, Standardization and Industrial Quality</td>
</tr>
<tr>
<td>INMET</td>
<td>Brazilian Institute of Meteorology</td>
</tr>
<tr>
<td>GREENSolar</td>
<td>Is the only Brazilian laboratory which is testing solar collectors for the INMETRO</td>
</tr>
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DEC  
Desiccant Evaporative Cooling
Open cycle air-conditioning process.
Central components: sorptive air dehumidification, using either solid or liquid sorption material; heat recovery unit; return (and often supply) air humidifiers. Requires separate supply and return air ducts.

COP  
Coefficient of Performance
Performance number of thermally driven chillers:
Ratio of (cold production) / (driving heat input) Used with power units (kW/kW) to provide rated values, or with energy units (kWh/kWh) to provide the performance during longer periods.

EER  
Electrical Efficiency Ratio
Performance number of electrically driven compression chillers: Ratio of (cold production) / (electricity input). Used with power units (kW/kW) to provide rated values, or with energy units (kWh/kWh) to provide the performance during longer periods.