Title: Energy Efficient Building Technologies in Hot Humid Climates

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Presentation Coverage

Part One - Introduction

Part Two - A Literature Review

Part Three - Methodology

Part Four - Results

Part Five - Comparative Analysis

Part Six - Conclusions & Recommendations
Problem Statement

State of Buildings Vs Energy Efficiency

Thermal Comfort Standards Vs Hot Humid Climate

Thermal Comfort Vs Energy Consumption

Extent Influence of Design Parameters not known
To explore energy efficient building technologies in HHC

To analyse the performance of existing buildings in HHC

To search for alternative construction techniques and materials

To provide options for designers in HHC on energy efficient BT
**Hot & Humid Climate Characteristics**

- Very little seasonal variations throughout a year.
- Air temperature reaches Mean Max. between 27-32°C.
- Air temperatures reaches Mean Min. between 21-27°C.

### Relative Humidity

#### Dar es Salaam Relative Humidity

- The relative humidity chart shows a general decrease in humidity from January to December, with slight variations.

### Temperature Variations

#### Dar es Salaam Temperature Variations

- The temperature chart indicates a consistent temperature range from January to December, with slight fluctuations.

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ISO 7730 PMV Model Vs Field Studies in Hot and Humid Climates

![Graph showing thermal comfort temperatures vs mean outdoor air temperatures for buildings with natural ventilation.](image)
Humphrey’s Equations

For Free-Running Buildings
(i) $T_c = 0.534T_o + 12.9^\circ C$....eqn. 1

Comfort Ranges: +/- 3°C

For Air-conditioned Buildings
(ii) $T_c = 0.16T_o + 18.6^\circ C$....eqn. 2

Comfort Ranges: +/- 1.5°C
Comfort Limits for Free-Running Buildings in a Hot and Humid Climate (Dar es Salaam)

- Linear (Tc=0.54To+12.9)
- Linear (Tfr-lowest comfort limit)
- Linear (Tfr-lower comfort limit)
- Linear (Tfr-upper comfort limit)
- Linear (Tfr-highest comfort limit)
Comfort Limits for Air-Conditioned Buildings in a Hot and Humid Climate (Dar es Salaam)

- Linear (Tc=0.16To+18.6)
- Linear (Tac-lower comfort limit)
- Linear (Tac-upper comfort limit)
Methodology: Case Studies from Dar es Salaam, Tanzania

Case Study 1-ACB    Case Study 2-FRB    Case Study 3-ACB    Case Study 4-ACB

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Methodology: General Observations

Cases II&IV - Free-Running Buildings

An increase in ventilation increases the indoor thermal comfort

Construction techniques influence the indoor thermal comfort

Case studies can not be used to draw conclusions due to some differences

Cases I&III - Air-Conditioned Buildings

Case I (double glazed) shows better indoor thermal conditions than Case III (single glazed)

Case I shows better energy consumption than Case III

Field data are necessary for comparison basis
Methodology: Parametric Models

Model I - Clay CEB's
Model II - Brickwork
Model III - Concrete HB
Model IV - Timber Panels
Model V - Granite Stone
Model VI - Polycarbonate
Model VII - Single Glazed
Model IX - Double Glazed
## Methodology: Parametric Models Analysis

### Parametric Models

<table>
<thead>
<tr>
<th>General Identification</th>
<th>Design Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Material Influence</td>
</tr>
<tr>
<td>Group</td>
<td>Specific Material</td>
</tr>
<tr>
<td>Clay</td>
<td>1 Earth Blocks</td>
</tr>
<tr>
<td></td>
<td>2 Brickwork</td>
</tr>
<tr>
<td>Concrete</td>
<td>3 Concrete Hollow Blocks</td>
</tr>
<tr>
<td></td>
<td>4 Concrete Blocks</td>
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<tr>
<td>Timber</td>
<td>5 Timber Panels</td>
</tr>
<tr>
<td>Stone</td>
<td>6 Granite</td>
</tr>
<tr>
<td>Plastic</td>
<td>7 Polycarbonate</td>
</tr>
<tr>
<td></td>
<td>8 ETFE Foils</td>
</tr>
<tr>
<td>Glass</td>
<td>9 Single Glazed</td>
</tr>
<tr>
<td></td>
<td>10 Double Glazed</td>
</tr>
<tr>
<td></td>
<td>11 Glass Blocks</td>
</tr>
<tr>
<td>Other</td>
<td>12 Water Facade</td>
</tr>
<tr>
<td></td>
<td>13 PCM</td>
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</table>

### General Identification

<table>
<thead>
<tr>
<th>Group</th>
<th>Specific Material</th>
<th>Orientation Influence</th>
<th>Load factor 0.5</th>
<th>Internal walls</th>
<th>As FRB&amp;ACB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>14 Earth Blocks</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Concrete</td>
<td>15 Concrete Blocks</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
Simulation Results as FRB

Influence of Design Parameters in a Free-Running Building

- Linear (Tfr-clay blocks)
- Linear (Tfr-shading)
- Linear (Tfr-o.25window size)
- Linear (Tfr-insulation)
- Linear (Tfr-lower comfort limit)
- Linear (Tfr-upper comfort limit)
Results: Parametric Model I - Clay Blocks (CEB’s)

Model Analysed: Simulation Results as ACB

Influence of Design Parameters in Air-Conditioned Building

- Linear (Tac-clay blocks)
- Linear (Tac-shading)
- Linear (Tac-0.25 window size)
- Linear (Tac-insulation)
- Linear (Tac-lower comfort limit)
- Linear (Tac-upper comfort limit)
Results: Parametric Model I - Clay Blocks

Model Analysed

Simulation Results as ACB

Influence of Design Parameters on Energy Demand

<table>
<thead>
<tr>
<th>Design Parameters on a Clay Facade</th>
<th>Annual Cooling Energy Demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay Blocks</td>
<td>4214</td>
</tr>
<tr>
<td>Shading</td>
<td>3721</td>
</tr>
<tr>
<td>Window Size</td>
<td>4032</td>
</tr>
<tr>
<td>Insulation</td>
<td>4163</td>
</tr>
</tbody>
</table>
CA - Influence of Façade Constructions on the Indoor Thermal Comfort (FRB)

Comparative Analysis of Constructions on a Free-Running Building

Comparative Analysis of Performance of Facades w.r.t. Thermal Properties in Free-running Building

- Glass blocks: 0.7, 8.7
- Single glazed: 1.7, 3.85
- Double glazed: 1.7, 4.09
- Timber panels: 2.64, 4.09
- Polycarbonate: 1.75, 3.63
- Clay blocks: 2.5, 4.02
- Brickwork: 1.9, 3.71
- Concrete blocks: 1.7, 3.61
- Concrete hollow blocks: 2.94, 0.39
- Granite stone: 2.94, 0.4

Thermal Transmittance Values (W/m²/K)

- U-total for façade
- U-value of material
CA-Influence of Façade Constructions on the Indoor Thermal Comfort (ACB)

Comparative Analysis of Constructions on Air-Conditioned Building

Comparative Analysis of Performance of Facades w.r.t Thermal Properties in Air-conditioned Building

- Single glazed
- Glass blocks
- Timber panels
- Granite stone
- Polycarbonate
- Clay blocks
- Brickwork
- Concrete blocks
- Double glazed
- Concrete hollow blocks

Outdoor Mean Temperatures [°C]

Comfort Temperatures [°C]

Thermal Transmittance Values (W/m²/K)

U-total for façade
U-value of material
Influence of Orientation on the Indoor Thermal Comfort and Energy Demand

Influence of Orientation on the Indoor Thermal Comfort of a Free-Running Building

Orientation Influence on Energy Demand

Design Parameters and Orientations

Outdoor Mean Temperatures [°C]

Comfort Temperatures [°C]

Linear (Tfr-upper comfort limit)
CA-Influence of Variation of Internal Load on Thermal Comfort

Influence of Internal Load in a Free-Running Building Comparative Analysis of Clay Model

Influence of Internal Load Variation in Air-Conditioned Building for a Clay Model

Outdoor Mean Temperature [°C]
- Linear (Tfr-clay blocks (50%))
- Linear (Tfr-shading (50%))
- Linear (Tfr-o.25 window size (50%))
- Linear (Tfr-insulation (50%))
- Linear (Tfr-upper comfort limit)

Outdoor Mean Temperatures [°C]
- Linear (Tac-clay blocks (50%))
- Linear (Tac-shading (50%))
- Linear (Tac-o.25 window size (50%))
- Linear (Tac-insulation (50%))
- Linear (Tac-upper comfort limit)
Comparative Analysis-Influence of Variation of Internal Load on Energy Demand

Influence of Variation of Internal Load on Energy Demand-
Comparative Analysis of a Clay Model

<table>
<thead>
<tr>
<th>Design Parameters on a Clay Façade</th>
<th>Annual Energy Demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay Blocks</td>
<td>4214, 3721</td>
</tr>
<tr>
<td>Shading</td>
<td>4057, 3410</td>
</tr>
<tr>
<td>Window Size</td>
<td>4032, 3841</td>
</tr>
<tr>
<td>Insulation</td>
<td>4163, 3992</td>
</tr>
</tbody>
</table>

Influence of Variation of Internal Load in Energy Demand- Comparative Analysis of a Timber Model

<table>
<thead>
<tr>
<th>Design Parameters on a Timber Façade</th>
<th>Annual Energy Demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Hollow Blocks</td>
<td>4259, 3799</td>
</tr>
<tr>
<td>Shading</td>
<td>4113, 3512</td>
</tr>
<tr>
<td>Window Size</td>
<td>4116, 3937</td>
</tr>
<tr>
<td>Insulation</td>
<td>4188, 4020</td>
</tr>
</tbody>
</table>

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CA - Influence of Variation of Internal Thermal Mass on the Indoor Thermal Comfort

Influence of Thermal Mass from Internal Walls in a Free-Running Building-Clay Facade

- Linear (Tfr-clay blocks (high internal thermal mass))
- Linear (Tfr-shading)
- Linear (Tfr-0.25window size)
- Linear (Tfr-insulation)
- Linear (Tfr-upper comfort limit)

Influence of Thermal Mass from Internal Walls in Air-Conditioned Building-Clay Facade

- Linear (Tac-clay blocks (high internal thermal mass))
- Linear (Tac-shading)
- Linear (Tac-0.25window size)
- Linear (Tac-insulation)
- Linear (Tac-upper comfort limit)
CA-Influence of Variation of Internal Thermal Mass on Energy Demand

Figure: Influence of variation of internal thermal mass on energy demand for clay & timber models

Design Parameters on Clay Façade

- Clay Blocks: 4057 kW(h)
- Shading: 3721 kW(h)
- Window Size: 3841 kW(h)
- Insulation: 3992 kW(h)

Design Parameters on a Timber Façade

- Timber panels: 4258-4259 kW(h)
- Shading: 3804-3799 kW(h)
- Window Size: 4114 kW(h)
- Insulation: 4185-4188 kW(h)
Comparative Analysis-By ATG–(Adaptive Temperature Limits) Method

Influence of Design Parameters in a Free-Running Building

Concrete Hollow Blocks Model- Annual Working Hours for a Free-Running Building with Shading

y = 0.31x + 22.8

Linear (Tfr-min(80% accept,))
Linear (Tfr-max(80% accept))
Linear (Tfr-max. with increased ventilation)
Linear (Tfr-min. with increased ventilation)
Linear (Tc(neutral))
Comparative Analysis by ATG—Influence of Design Parameters on Cooling Energy Demand

![Bar Chart Comparing Energy Savings for Different Design Parameters](chart.png)

**Parametric Models of Study**
- **0.25 Window Size Variation**
- **Shading Device in Use**
- **Insulation**

**Percentage of Energy Saved (GI)**
- Granite stone: 11%
- Concrete hollow blocks: 7%
- Concrete blocks: 5%
- Brickwork: 4%
- Clay blocks: 2%
- Polycarbonate: 12%
- Timber panels: 13%
- Single glazed: 18%
- Glass blocks: 17%
- Double glazed: 13%
Summary of Conclusions for FRB ’s

The performance of the Façade constructions depends on the total thermal transmittance

Internal walls with high thermal mass has negative influence on the indoor thermal comfort for FRB

Design parameters e.g. shading & window size variation have significant influence on the indoor thermal comfort for FRB

Orientation has insignificant influence on the indoor thermal comfort except for South Orientation

Insulation has insignificant influence on the indoor thermal comfort of FRB

Insulation has insignificant influence on the indoor thermal comfort of FRB

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Summary of Conclusions for ACB’s

Façade constructions exhibit distinct performance in ACB

Design parameters reduce energy annual cooling energy demand by 11%-18%

Insulation has insignificant influence on reduction of cooling energy demand

Internal partitions influence on the cooling energy demand depends on the type of external facade

Reduction of internal load has minor but significant influence on the cooling energy demand -3%
<table>
<thead>
<tr>
<th><strong>Free-Running Buildings</strong></th>
<th><strong>For Air-Conditioned Buildings</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design of façade construction has to consider the total thermal transmittance ((U)). A range of 2-3.5 (2-3.5) (\text{Wm}^2/\text{K}) is recommended.</td>
<td>A consideration for the total thermal transmittance is recommended specifically for masonry construction. The total cooling energy demand is proportional to the ((U))</td>
</tr>
<tr>
<td>The use of design parameters e.g. shading &amp; window size variations is recommended. Shading can keep FRB below 80% accept. for 90% of the annual working hours.</td>
<td>Design parameters are recommended due to their influence on reduction of energy. The extent varies from 11%-18% of annual cooling energy.</td>
</tr>
<tr>
<td>When glass is necessity, double glazed is highly recommended than the rest.</td>
<td>Insulation use is not recommended due to insignificant influence on energy demand. The extent varies from 0% - 1%.</td>
</tr>
<tr>
<td>Insulation use is not recommended in HHC/FRB since it hinders loss of heat when the outdoor temperature is lowered.</td>
<td>Among glazed materials, double glazed is recommended for use. Single glazed and glass blocks are not recommended</td>
</tr>
</tbody>
</table>
End of the Presentation!!!

Thank you!!!

Dank u wel !!

Ahsante!