



COMPARATIVE LIFE-CYCLE COST ANALYSIS OF REFRIGERATION SYSTEMS IN ICE RINKS

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Introduction

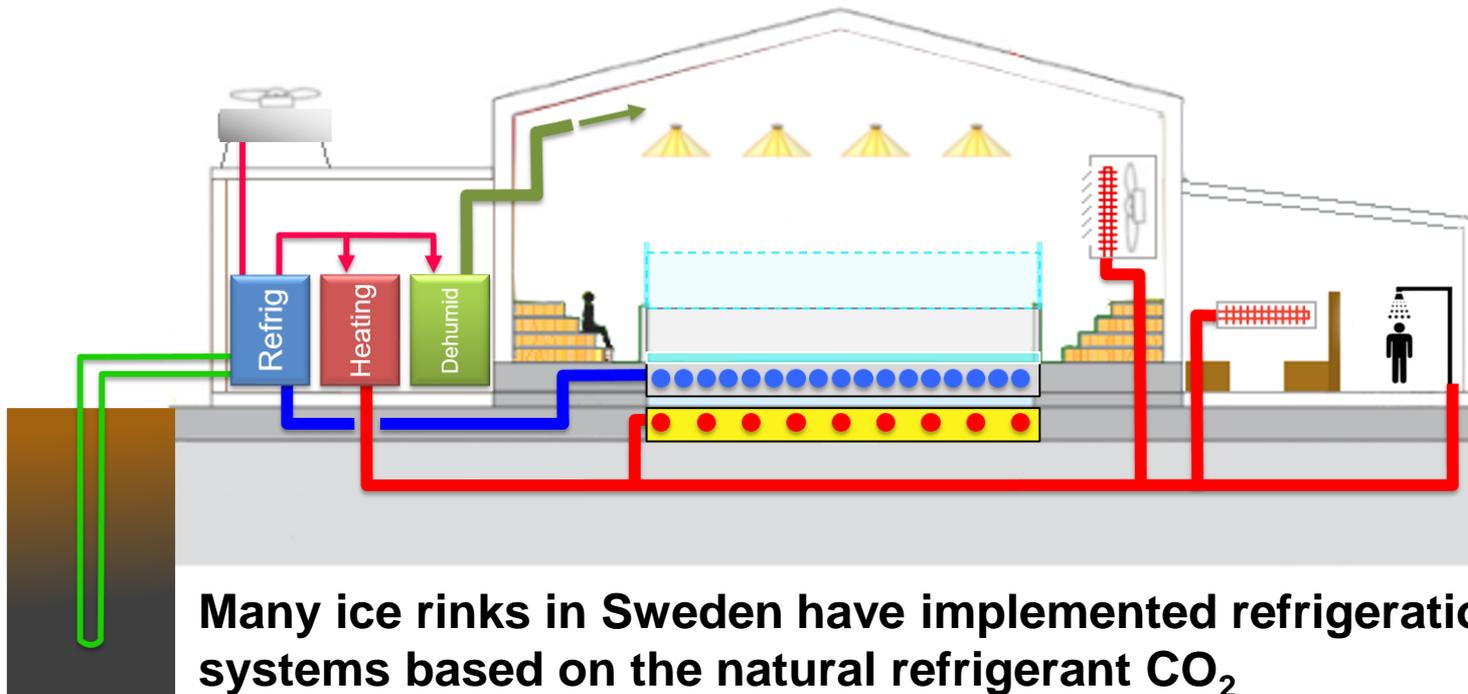
Many ice rinks must undergo renovation

Popular refrigerants in EU ice rinks no longer fulfill the Global Warming Potential (GWP)-requirements set by the F-gas Regulation

➤ E.g. R-22 and R-404A

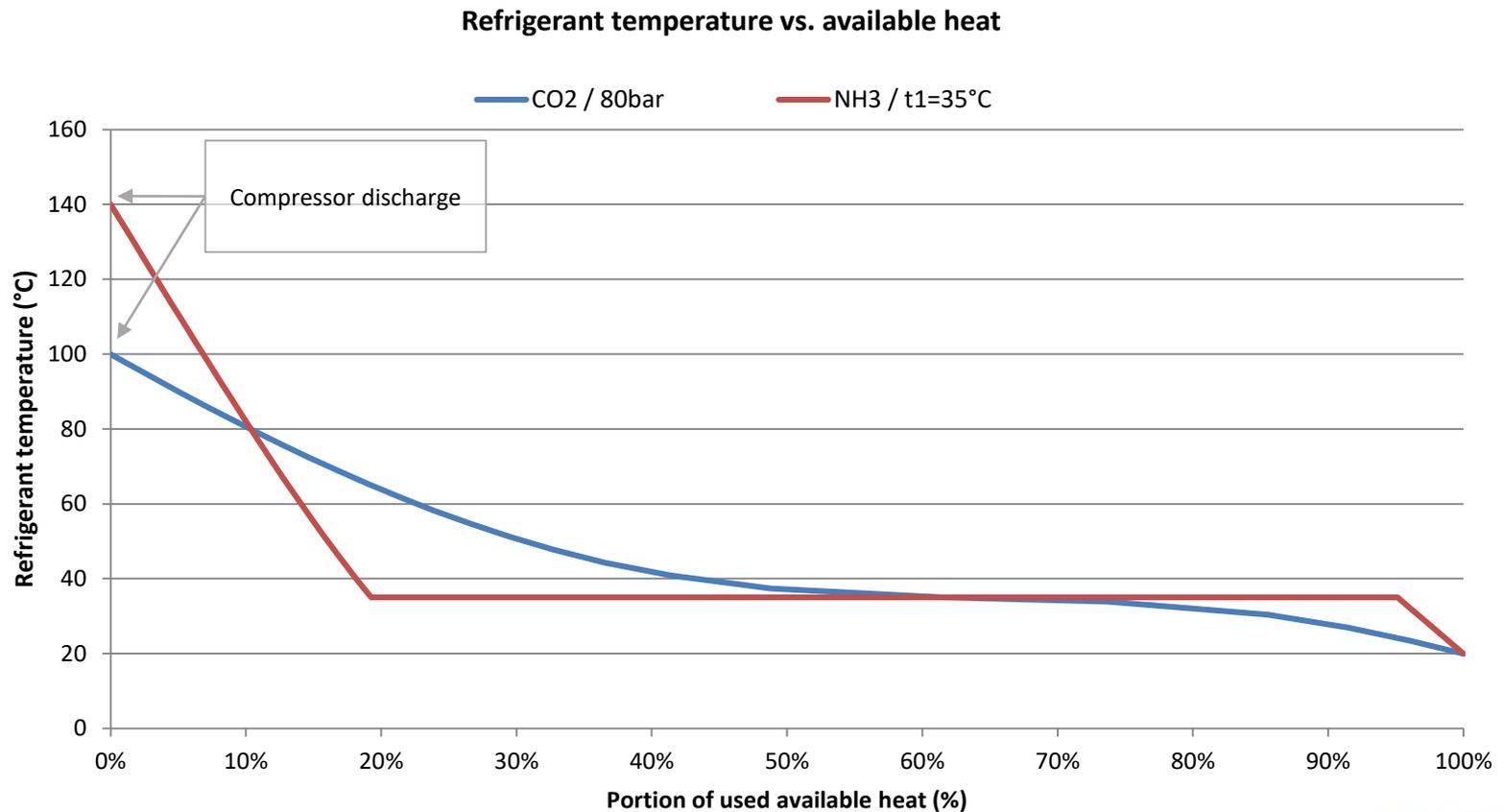
Subsequent renovations will require sound financial decision-making in order to improve overall performance

CO₂-based systems becoming popular



- Energy consumption went down, in some cases by half
- Due to CO₂ properties, some ice rinks became self-sufficient on recovered heat
 - *Heat export possible*

Heat recovery potential of CO₂



Problem, objective & scope

Missing:

- A practical and reliable way to incorporate life-cycle cost (LCC) analysis when comparing refrigeration systems in ice rinks

Solution:

- Develop an LCC analysis model that is effective and capable of producing reliable results when comparing refrigeration systems in ice rinks
 - Focus on financial performance
 - Heat recovery performance is included

LCC analysis model

Model structure & input data

Developed in Excel

- Programmed macro commands
- Automatic calculations and LCC analysis

Input data gathered from various sources

- Energy use model (Bolteau et al.)
 - Including released heat
- Cost breakdown
 - Investment
 - Yearly and periodic service cost

System 1

Summary

Heating systems active

Hot tap water
Dehumidification
Radiators, convectors
Ventilation
Floor heating
Perimeter protection

Step 1: Select a heat source to accompany the refrigeration system

No heating District heating
 Heat pump Heat recovery
 Heat recovery & Geothermal storage
 Heat recovery & District heating
 Heat recovery & Heat export
 Heat recovery & District heating & Geothermal storage
 Heat recovery & District heating & Geothermal storage & Heat export
 Heat recovery & District heating & Geothermal storage & Heat export & Heat export
 Heat recovery & District heating & Geothermal storage & Heat export & District heating

Step 2: Modify the distribution system

Heat recovery & Heat pump
 Heat recovery & Heat pump & Geothermal storage
 Heat recovery & Heat pump & Geothermal storage & Heat export
 Heat recovery & Heat pump & District heating
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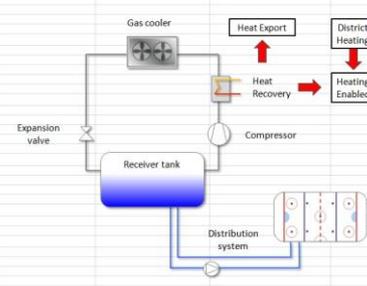
Selected settings

Distribution system
 Header material: Copper
 Risk piping material: Copper
 Thermal concrete layer: Disabled
Heat recovery
 Heat recovery: Enabled
 Geothermal storage: Disabled
 Heat export: Enabled
 External heat source: District heating

System summary

Starting point		
Investment cost	709700	SEK
Economic lifespan	20	Years
COP		
Refrigeration		
Heating	3.8	
Combined		
Energy consumption per year		
Refrigeration		MWh
Heating		MWh
Total	344	MWh
Life-cycle costs		
Investment life-cycle cost	709525	SEK
Operation life-cycle cost	406110	SEK
Yearly service life-cycle cost	128405	SEK
Periodic service life-cycle cost	49231	SEK
Total life-cycle cost	1118270	SEK
Equivalent Annual Cost		
Investment annual cost	452271	SEK
Operation annual cost	289554	SEK
Yearly service annual cost	81044	SEK
Periodic service annual cost	15360	SEK
Total Annuity	854129	SEK

Selected system



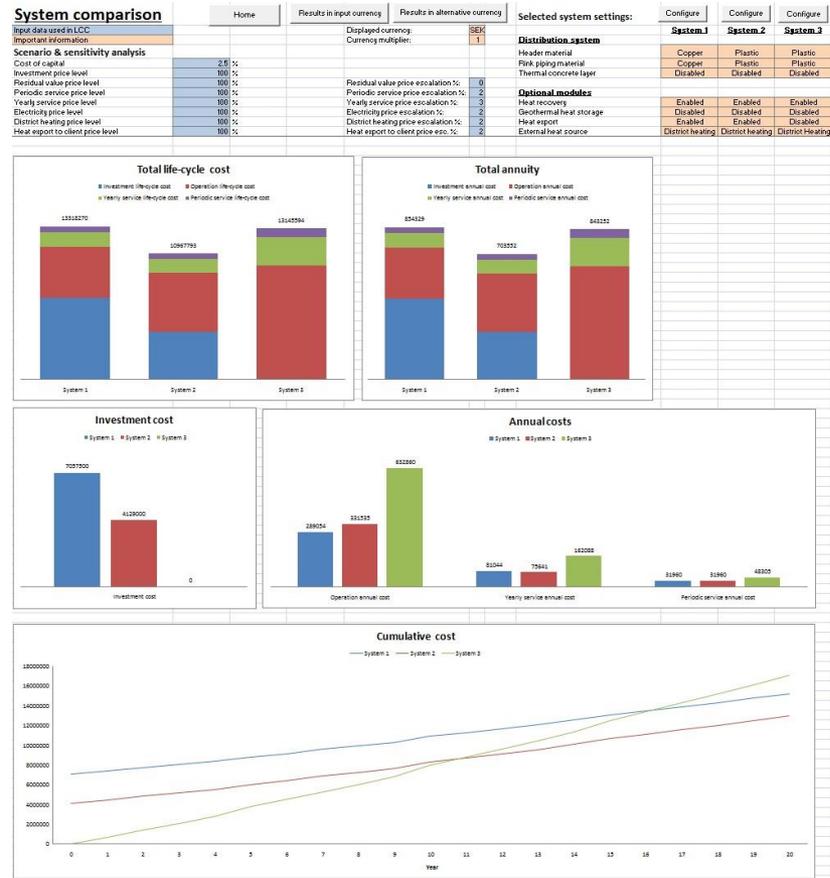
System comparison

System solutions are compared simultaneously

- Investment cost
- Annual cost
- Total life-cycle cost
- Equivalent annual cost
- Cumulative cost

Live sensitivity and scenario analysis

- Evaluates quality of input data
- Tests robustness of analysis results



Case examples & Results

Three case examples

Ice rinks located in Sweden

- Existing systems were reviewed
- Refrigeration and heating demands were estimated

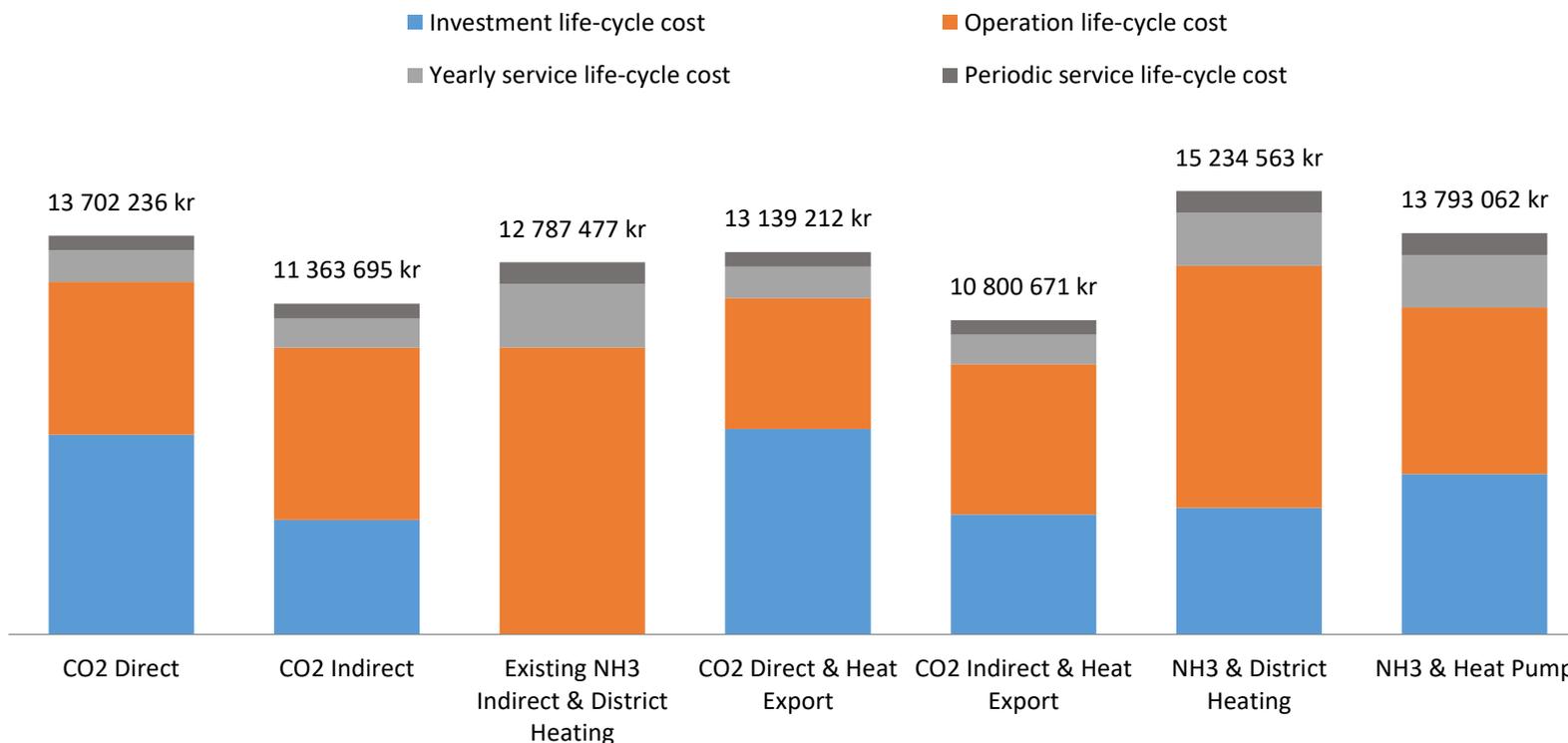
New alternatives were proposed

- Systems based on CO₂ and NH₃
 - With additional options, e.g. heat export
- LCC calculations were done in model for all refrigeration systems
- Comparison with existing system



LCC results: Case X

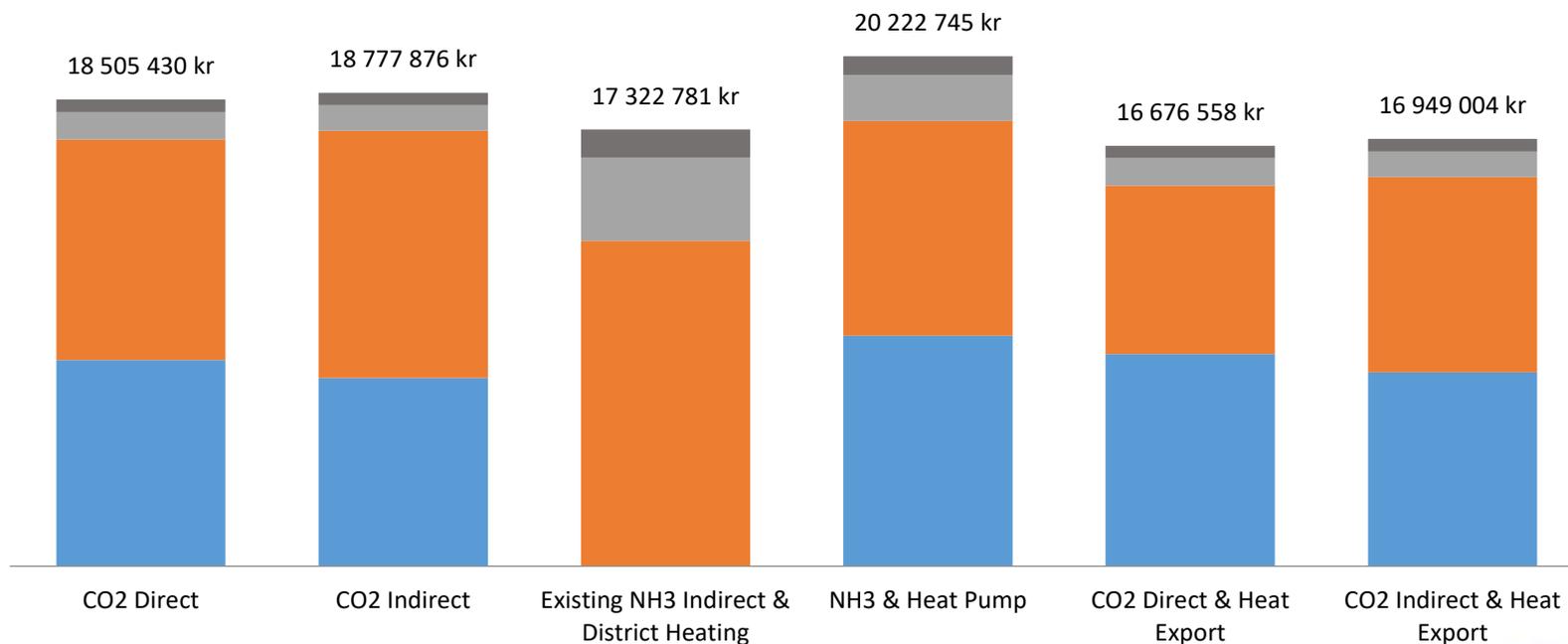
Total life-cycle cost



LCC results: Case Y

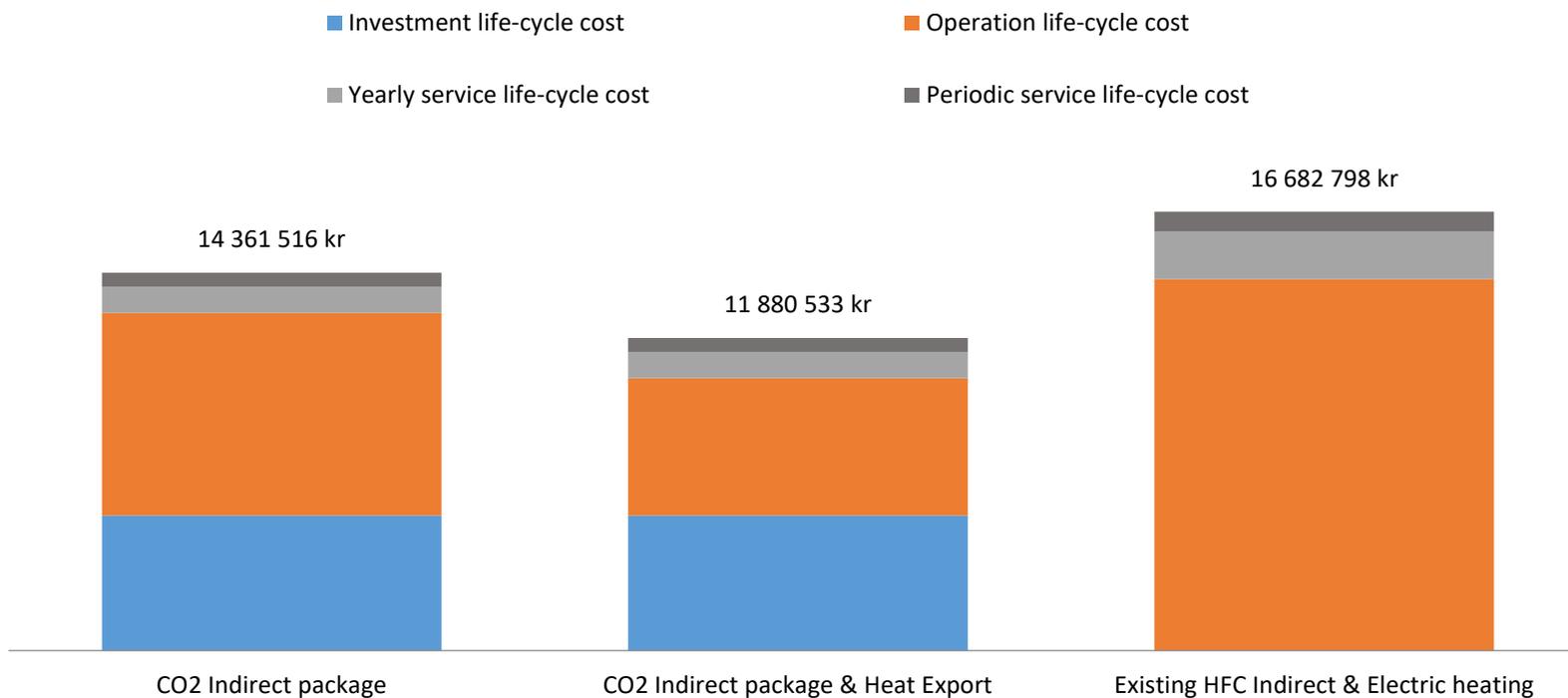
Total life-cycle cost

■ Investment life-cycle cost
 ■ Operation life-cycle cost
 ■ Yearly service life-cycle cost
 ■ Periodic service life-cycle cost



LCC results: Case Z

Total life-cycle cost



Conclusions

Conclusions

Sensitivity and scenario analysis plays a crucial role when evaluating the quality of input data

The reliability of the results can be assessed in the model

- The model is applicable and effective in comparative LCC analysis of refrigeration systems in ice rinks

Refrigeration systems based on CO₂ with optimized heat recovery seem to have a competitive advantage in ice rinks

- In investment
- In service
- In overall energy cost

Thank you!

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