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IEA Joint Project SHC Task 42/ ECES Task 24: Advanced Materials for Compact Thermal Energy Storage

W. Streicher

Berichte aus Energie- und Umweltforschung

21/2012

Dynamik mit Verantwortung

Impressum:

Eigentümer, Herausgeber und Medieninhaber:
Bundesministerium für Verkehr, Innovation und Technologie
Radetzkystraße 2, 1030 Wien

Verantwortung und Koordination:
Abteilung für Energie- und Umwelttechnologien
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IEA Joint Project SHC Task 42/ ECES Task 24: Advanced Materials for Compact Thermal Energy Storage

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AIT

Wien, Oktober 2010

Ein Projektbericht im Rahmen der Programmlinie

IEA FORSCHUNGS KOOPERATION

Impulsprogramm Nachhaltig Wirtschaften

Im Auftrag des Bundesministeriums für Verkehr, Innovation und Technologie

Vorbemerkung

Der vorliegende Bericht dokumentiert die Ergebnisse eines Projekts aus dem Programm FORSCHUNGSKOOPERATION INTERNATIONALE ENERGIEAGENTUR. Es wurde vom Bundesministerium für Verkehr, Innovation und Technologie initiiert, um Österreichische Forschungsbeiträge zu den Projekten der Internationalen Energieagentur (IEA) zu finanzieren.

Seit dem Beitritt Österreichs zur IEA im Jahre 1975 beteiligt sich Österreich aktiv mit Forschungsbeiträgen zu verschiedenen Themen in den Bereichen erneuerbare Energieträger, Endverbrauchstechnologien und fossile Energieträger. Für die Österreichische Energieforschung ergeben sich durch die Beteiligung an den Forschungsaktivitäten der IEA viele Vorteile: Viele Entwicklungen können durch internationale Kooperationen effizienter bearbeitet werden, neue Arbeitsbereiche können mit internationaler Unterstützung aufgebaut sowie internationale Entwicklungen rascher und besser wahrgenommen werden.

Dank des überdurchschnittlichen Engagements der beteiligten Forschungseinrichtungen ist Österreich erfolgreich in der IEA verankert. Durch viele IEA Projekte entstanden bereits wertvolle Inputs für europäische und nationale Energieinnovationen und auch in der Marktumsetzung konnten bereits richtungsweisende Ergebnisse erzielt werden.

Ein wichtiges Anliegen des Programms ist es, die Projektergebnisse einer interessierten Fachöffentlichkeit zugänglich zu machen, was durch die Publikationsreiche und die entsprechende Homepage **www.nachhaltigwirtschaften.at** gewährleistet wird.

Dipl. Ing. Michael Paula
Leiter der Abt. Energie- und Umwelttechnologien
Bundesministerium für Verkehr, Innovation und Technologie

Kurzfassung

Das österreichische Konsortium hat in diesem Projekt folgenden Beiträge für den Task/Annex geliefert:

- Mitarbeit in der Task Definition Phase bei der Erstellung des Workplans und Einbringung der österreichischen Expertise
- Leitung der Arbeitsgruppe „System Integration“
- Inhaltliche Arbeiten im Bereich Wärmespeicherung:
    - Von **AEE INTEC** wurde ein aus dem Task 32 vorhandenes Simulationsmodell für einen geschlossenen Sorptionsspeicher so umgebaut, dass sowohl Heizung als auch Warmwasserbereitung gedeckt werden können und der konventionelle Pufferspeicher (Wasser), der im Modell für die Task 32 noch enthalten war, entfallen kann. Simulationsergebnisse lagen zum Zeitpunkt der Berichtserstellung noch nicht vor. Im weiteren Verlauf des Tasks ist geplant, das Simulationsmodell mit Materialkenndaten von im Rahmen des Tasks neu entwickelten Materialien laufen zu lassen und somit das Potential der neuen Materialien für diese Anwendung (saisonale Speicherung von Solarwärme für Raumheizung und Warmwasserbereitung in einem Niedrigenergie-Einfamilienhaus) abschätzen zu können.
    - Das **AIT** untersuchte im Rahmen des Projekts die Möglichkeiten des Einsatzes von Thermochemischen Speichern in Nahwärmenetzen in Kombination mit Absorptionskältemaschinen oder Desiccant Cooling Systemen (DEC). Nach einer ausführlichen Recherche der vorhanden Technologien und der vorhanden Simulationsmodelle von thermochemischen Speichern wurde eine Simulation der Wärmenetze mit diesen Komponenten durchgeführt.

Am **Institut für Wärmetechnik der TU Graz** wurden im Rahmen des Projekts Simulationsrechnungen mit den im IEA SHC Task 32 definierten Randbedingungen durchgeführt, die das Potenzial einer Integration von Phasenwechselmaterialien (PCM) in den Wärmespeicher eines solaren Kombisystems für Warmwasserbereitung und Heizungsunterstützung aufzeigen. Die Ergebnisse zeigen, dass der solare Deckungsgrad, bzw. der spez. Solarertrag der Solaranlage durch die Integration eines gängigen PCM in den Speicher gegenüber einem konventionellen Wasserspeicher verbessert werden kann. Diese Verbesserung ist bei Systemen mit hohen solaren Deckungsgraden, die in Richtung saisonale Wärmespeicherung tendieren, viel stärker ausgeprägt als bei Konfigurationen mit einem niedrigen Deckungsgrad. Die Simulationen ergeben, dass eine solare Volldeckung des Wärmebedarfs mit einem PCM-Speicher bereits mit einem wesentlich kleineren Speichervolumen erreichbar ist als mit einem Wasserspeicher.

Inhalt

I. Informationen zum IEA-SHC/ECES Task/Annex 4224

I.1 Motivation und Zielsetzung

Wärmespeicherung ist eine wichtige Technologie zur Erhöhung der Nutzung Erneuerbarer Energieträger. Durch die Verbesserung des Speicherwirkungsgrads kann auch der Wirkungsgrad der Nutzung erneuerbarer Energieträger erhöht werden. Insbesondere für solarthermische Systeme, die hohe Deckungsgarde erreichen, sind Langzeitwärmespeicher oder Kältespeicher unabdingbar. Hier werden Wasserspeicher sehr groß und damit teuer. Alternative Speicher wie PCM-Speicher, die z.B. die Unterkühlung bewusst ausnutzen, um keine Langzeit-Temperaturverluste zu haben, aber auch thermochemische Speicher sind im Labormaßstab verfügbar. Außerdem wurden im Vorfeld bereits erste Simulationsmodelle erarbeitet, anhand derer die Speicher simulationstechnisch in Anwendungssysteme eingebaut und so die Wirkungsweise über ein ganzes Jahr berechnet und mit der Wirkungsweise und Effizienz von Wasserspeichern verglichen werden können.

Es ist noch intensive Forschung notwendig, bevor diese Technologien in kommerziellen Anwendungen umgesetzt werden können. In einigen laufenden und abgeschlossenen IEA Annexen wurde festgestellt, dass die Materialien die Hauptschwierigkeit für effiziente Lösungen für kompakte Wärmespeicher darstellen und daher Materialien mit höherer spezifischer volumetrischer Wärmekapazität und geringen Kosten sowohl für Kurzzeit- als auch insbesondere für Langzeitspeicher notwendig sind.

Wärmespeicherung wurde auch in Österreich als wichtiges Thema für die zukünftige Energieforschung erkannt. Im Diskussionspapier zum Strategieprozess ENERGIE 2050 (der Vorläuferprozess zur Forschungsschiene „Energie der Zukunft“ des BMVIT) ist die Energiespeicherung in den meisten Themenfeldern integraler Bestandteil. Insbesondere im Themenfeld „Fortschrittliche Verbrennungs- und Umwandlungstechnologien“ wird die Energiespeicherung als zentraler Bestandteil gesehen.

Auch im Positionspapier für ein österreichisches Solarforschungs- und Technologieprogramm der Österreichischen Solarthermie Technologie Plattform (ASTTP) wird die Wärmespeicherung als ein notwendiger Forschungsschwerpunkt für Österreich erachtet.

Im vorliegenden Projekt wird die Teilnahme des österreichischen Konsortiums bestehend aus TU Graz, Institut für Wärmetechnik, AEE INTEC und AIT am Joint Tasks/Annex: IEA-SHC Task 42 „Advanced Materials for Compact Thermal Energy Storage" und IEA ECES Annex 24 „Material Development for Improved Thermal Energy Storage Systems“ finanziert. Ziel dieser internationalen Kooperation ist die Entwicklung von fortschrittlichen Materialien für kompakte Wärmespeichersysteme für Heizen und Kühlen mittels erneuerbarer Energieträger und zur Energieeinsparung. Im folgenden werden die beiden beteiligten Implementing Agreements kurz beschrieben:

- **Implementing Agreement on Solar Heating and Cooling (SHC)**

Eines der ersten Implementing Agreements im Rahmen der IEA war das 1977 gestartete „Solar Heating and Cooling Programme“ (SHC). Es wurden in Summe bisher 39 Tasks im Bereich aktive und passive Sonnenenergienutzung für Heizen und Kühlen von Gebäuden sowie Photovoltaik durchgeführt. Durch die Teilnahme von 21 Ländern und der Europäischen Kommission ist in diesem Forschungsprogramm ein breiter internationaler Erfahrungsaustausch möglich.

Das SHC Programm bearbeitet die folgenden Schwerpunke:
- Verbesserung bestehender Technologien.

- Erhöhung der Wirtschaftlichkeit von Produkten
- R&D für neue Materialien und Prozesse, um die Energieeffizienz von Gebäuden durch die Sonnenenergienutzung zu verbessern (z.B. elektrochrome und thermochrome Materialen zur Kontrolle der Transmissivität von Fenstern, Phasenwechselmaterialien, Wärmespeichermaterialien, transparente Wärmedämmung)
- Verbesserung der Integration und Optimierung von solaren Komponenten (Photovoltaik und Solarthermie) in energieeffizienten Gebäude
- Testen und Zertifizieren von Komponenten und Produkten
- Erarbeiten und Verbreiten von Informationsmaterial für Interessierte und Entscheidungsträger
- Erhebung und Verbreitung von belastbaren weltweiten Statistiken über die Verfügbarkeit von Solarenergie und die Technologien zur Nutzung derselben

• Implementing Agreement on Energy Conservation Through Energy Storage (ECES)
Dieses Implementing Agreement ist eine Forschungs- und Entwicklungszusammenarbeit welche 1978 zwischen einer Reihe von IEA Teilnehmerländern gestartet wurde. Ziel ist die gemeinsame Forschung, Entwicklung, Demonstrierung und Informationsaustausch im Bereich Energieeinsparung durch Energiespeicherung. Der volle Titel lautet: "Programme of Research and Development on Energy Conservation through Energy Storage". Derzeit nehmen 19 Länder (darunter USA, Kanada, Japan, Deutschland, Korea und die Türkei) sowie die Europäische Union an diesem Implementing Agreement teil. Österreich ist noch nicht darunter.

Es wurden bisher 21 Annexe bearbeitet, 4 Annexe laufen derzeit.

Der Bereich der Arbeiten umfasst Kurz- und Langzeitwärmespeicher mit verschiedenen Materialien (Wasser, Aquifere, Erdreich, Phasenwechselmaterialien) sowie Stromspeicher. Die Anwendungen gehen von Gebäuden zum Heizen und Kühlen über Industrie bis hin zu transportablen Wärmespeichern.

Im neuen Task soll der Bereich auch auf chemische Speicher und Sorptionsspeicher erweitert werden.

I.2 Geplante inhaltliche Arbeiten des IEA-SHC/ECES Task/Annex 4224

Ziel dieser internationalen Kooperation ist die Entwicklung von fortschrittlichen Materialien und Systemen für kompakte Wärmespeichersysteme. Die Arbeit kann in 8 Hauptpunkte unterteilt werden:

- Identifikation von Materialanforderungen für relevante Anwendungen unter Verwendung von Simulationen bisher bekannter Speichertechnologien und der bisher in IEA-SHC Task 32 entwickelten Speichermodelle.
- Identifikation, Design und Entwicklung neuer Materialien und Verbundstoffe für kompakte Wärmespeicher,
- Entwicklung von Mess- und Testverfahren zur Charakterisierung der Sicherheit und Langzeitbeständigkeit der neuen Speichermaterialien,
- Verbesserung der Wirksamkeit, Stabilität und Wirtschaftlichkeit der neuen Speichermaterialien,
- Entwicklung von mehrdimensionalen numerischen Modellen, welche die Wirksamkeit der neuen Materialien beschreiben und die Möglichkeit zum Vergleich mit herkömmlichen Speichermaterialien eröffnen,
- Entwicklung und Demonstration neuer kompakter Speicherkonzepte für diese Materialien,

- Untersuchung der Auswirkungen der neuen Speichermaterialien auf den Wirkungsgrad von Wärmespeichern für unterschiedliche Anwendungen,
- Die Ergebnisse sollen über nationale Workshops, nationale und internationale Tagungen sowie Beiträge in wissenschaftlichen Journals und einschlägigen Fachzeitschriften der interessierten Öffentlichkeit und Firmen zugänglich gemacht werden.

Ein weiteres Hauptziel liegt in der Bildung eines aktiven und effizienten Wissenschaftsnetzwerks in dem Wissenschaftler und Industrievertreter aus dem Bereich der Wärmespeicherung miteinander kollaborieren können.

Methodik

In dem Task werden zwei verschiedene Personengruppen an dem gemeinsamen Ziel der verbesserten Wärmespeicherung mitarbeiten:

- Materialwissenschaftler, um Materialien mit besseren Eigenschaften zu finden
- Speicher- und Anlagen/Systemtechnikexperten

Um diese beiden Gruppe erfolgversprechend zusammenzubringen, wird die folgende Methodik angewendet:

- Materialwissenschaftler
  Diese Gruppe wird sich um die Analyse bestehender Stoffgruppen kümmern, diese auf Ihre Eignung als Wärmespeicher mit besseren Eigenschaften als Wasser (Wärme- und Stoffaustausch, Korrosivität, Toxizität, Kosten, etc.) prüfen, sowie Methoden zur Erzeugung dieser Materialien versuchen zu finden. Auch wird die Synthese von neuen Materialien und Verbundstoffen sowie deren Charakterisierung bearbeitet und deren Eigenschaften geprüft.

- Numerische Modellierung
  Numerische Modellierung der Materialien mit ihren intermolekularen Eigenschaften, Wärme- und Stofftransport und Verhalten in größeren Mengen.

- Speicher- und Anlagen/Systemtechnikexperten
  Entwicklung, Modellierung und Testen von Prototypen von neuen Wärmespeichern mit diesen Wärmespeichermedien sowie simulationsmäßige Implementierung dieser Wärmespeicher in komplette Anwendungssysteme mit Hydraulik, Regelung etc.

Innerhalb der IEA sind die beiden angesprochenen Gruppen (Materialwissenschaftler und Anwendungen thermischer Solaranlagen) in unterschiedlichen Implementing Agreements der IEA tätig (Materialwissenschaftler in ECES und Solaranlagenexperten in SHC). Nachdem im vorliegenden Task diese Arbeitsgruppen gemeinsam Lösungen finden sollen, wird diese Arbeit als Joint Task von beiden Implementing Agreements geführt werden.

Die folgenden Anwendungen sollen vom Start des Task/Annexs weg untersucht werden:

- Saisonale Wärmespeicherung,
- Cogeneration, Trigeneration and Wärmepumpenanwendungen,
- Gebäudeklimatisierung,
- Fern- und Nahwärmenetze,
- Industrielle Abwärme und

- Konzentrierende thermische Kollektoren zur Stromerzeugung.

Die Temperaturstabilisierung für z.B. Medikamente wird als interessante Zukunftsentwicklung ebenfalls betrachtet.
Obige Aufzählung und Einteilung ist aber flexibel zu sehen. Wenn sich andere interessante Anwendungen während des Tasks ergeben, können sie jederzeit später aufgenommen werden. Umgekehrt können auch Anwendungsgebiete herausgenommen werden, sollte sich eine geringere Attraktivität herausstellen. Folgende Struktur des Tasks/Annexes erlaubt diese Flexibilität.

I.3 Inhaltliche und organisatorische Struktur des IEA SHC/ECES Task/Annex 4224

Der Task ist in 2 Subtasks organisiert, die matrixartig ineinander verschränkt sind (siehe Abbildung 1). Jeder Subtask besteht aus mehreren Arbeitsgruppen. Durch diese Struktur soll

- die bestmögliche Verschränkung von Materialwissenschaftlern und Anwendungsexperten gewährleistet werden.
- der Informationsfluss zwischen den verschiedenen Arbeitsgruppen maximiert werden
- den unterschiedlichen Backgrounds und Arbeitsweisen der beiden Implementing Agreements dieses Joint Tasks gerecht werden

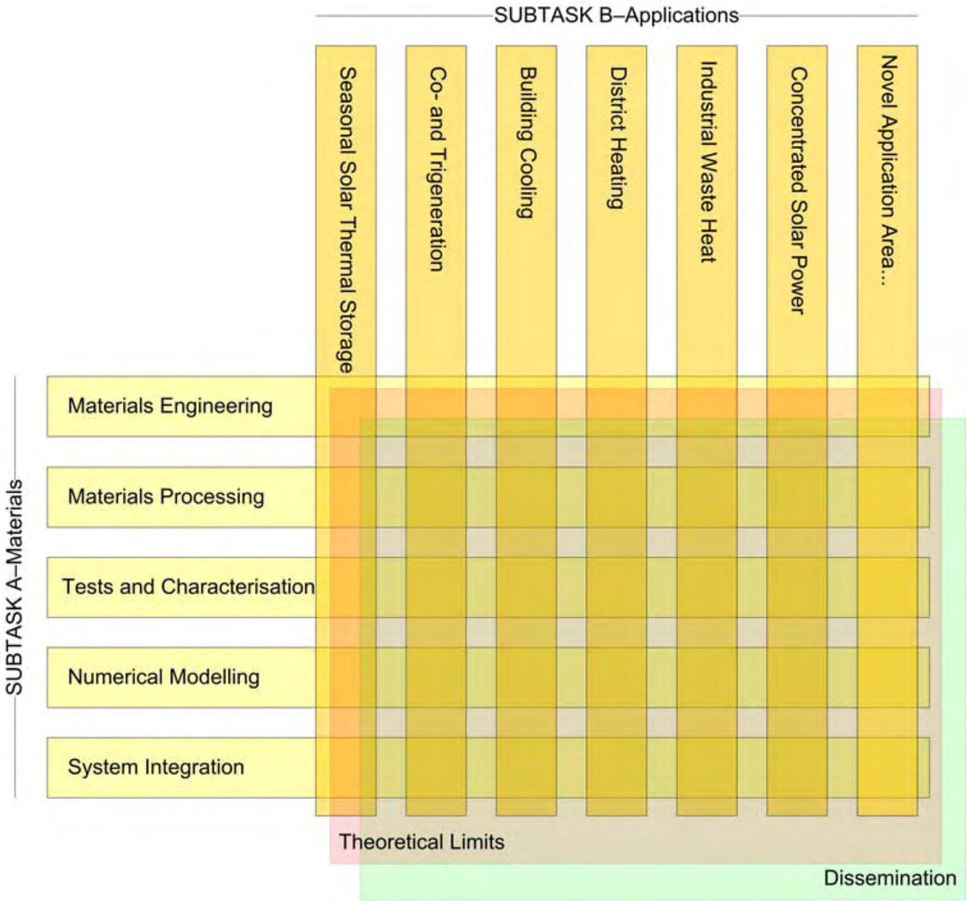

Abbildung 1: Matrixorganisation des Task/Annex 4224.

Operating Agents:
IEA-SHC: ECN, Niederlande, Wim van Helden (vanhelden@ecn.nl) und
ECES: ZAE Bayern, Deutschland, Andreas Hauer (hauer@muc.zae-bayern.de).

Subtask A: **Materials**
Subtask Leader: ZAE Bayern, Deutschland, Andreas Hauer (hauer@muc.zae-bayern.de)

Subtask B **Applications**
Subtask Leader: ECN, Niederlande, Wim van Helden (vanhelden@ecn.nl)

Die Arbeitsgruppenleiter wurden z.T. am letzten Task Meeting vom 11.-13. Februar 2009 in Bad Tölz, Deutschland bestimmt. Die Arbeitsgruppenleiter von Subtask A sollten fix bleiben, in Subtaks B könnten je nach Projektmittel und Erkenntnissen während des Tasks auch Wechsel der Leiter bzw. auch Wechsel der gesamten Arbeitsgruppen stattfinden. Im Bedarfsfall kann auch der Subtaskleader von Subtask B die Arbeitsgruppe mit übernehmen.

Subtask AB1 Subtask AB1 ist für die Verbreitung der Ergebnisse bei stakeholdern der Entwicklung von Wärmespeichern (Wissenschaftler, Industrie und Politik) sowie die internationale Netzwerkbildung verantwortlich.

Subtask AB2 Subtask AB2 beschäftigt sich mit theoretischen Grenzen von Materialien für kompakten Wärmespeichern und Systeme aus physikalischer, technischer und ökonomischer Sicht.

Teilnehmende Staaten:
Australien, Dänemark, Deutschland, Finnland, Frankreich, Großbritannien, Kanada, Niederlande, Österreich, Schweden, Schweiz, Spanien

Im Folgenden ist der vorläufige Zeitplan für den ECES Annex 24 bis Dezember 2009 dargestellt.

Phase 1 Juli 2008 – Dezember 2008
- Sammeln von Informationen über laufende Aktivitäten in diesem Bereich
- Aufbauen von gemeinsamen Aktivitäten
- Erster Wokshop und Experts Meeting
- Einrichten von Subtasks (PCM, thermochemische Speicher, Sensible Speicher …)

Phase 2 Januar 2009 – Juni 2009
- Zusammenstellen des Standes der Technik bei materialbezogener F&E für thermische Energiespeicher
- Identifizieren der Hauptziele für zukünftige F&E
- 2. Workshop und Experts Meeting

Phase 3 Juli 2009 – Dezember 2009
- Identifizieren von Anforderungen an „ideale“ Materialien in den Subtasks basierend auf den Erfahrungen in Pilot- Demonstrations- und Simulationsprojekten
- Beginn des Aufbaus einer Datenbank über neuartige Materialien und ihre Eigenschaften
- 3. Workshop und Expert Meeting

Um einen effektiven Fortschritt zu erzielen, sollten die teilnehmenden Organisationen mindestens ein halbes Mannjahr pro Jahr kalkulieren. Diese Arbeitsleistung teilt sich sowohl in organisatorische Arbeit (Teilnahme an Treffen, Beiträge für Reports etc.) als auch wissenschaftliche Arbeit für den Task.

Der aktuelle **Workplan vom Mai 2009 liegt als Anhang 1 bei**

I.4 Überblick über bisherige Aktivitäten

Im Folgenden werden die bisherigen Aktvitäten der Definitionsphase sowie der zukünftige Zeitplan des Tasks dargestellt.

1. Task Definition Meeting, Oktober 2007

Am 5. Oktober 2007 hat ein erstes Task Definition Meeting im Anschluss an das IEA-SHC Task 32 Abschlussmeeting in Zürich stattgefunden, an dem das IWT durch Wolfgang Streicher und die AEE-INTEC (Dagmar Jähnig) anwesend waren und ihre Vorstellungen zum Inhalt des neuen Tasks eingebracht haben. An dem Treffen waren Proponenten aus den Implementing Agreements IEA-SHC und IEA ECES beteiligt. Außerdem waren Firmenvertreter unter anderem von EDF (FR), Ciba Specialty Chemicals (UK), Acciona Infraestructuras (SP), and Vaillant Group (DE) vertreten. Alle Beteiligten waren sich über die Wichtigkeit des Themas thermische Wärmespeicherung einig und sahen die nächsten Schritte insbesondere in der Materialfrage. Die Industrievertreter sahen die thermische Wärmespeicherung nicht als Nischenmarkt sondern als essentiell für die weitere Entwicklung. Ein Protokoll des Meetings findet sich im **Anhang 2.**

November—Dezember 2007

Der neue Task wurde dem SHC ExCo bei seinem Meeting in Malmø am 6. und 7. Dezember 2007 und parallel dem ECES ExCo bei seinem Treffen in Ankara am 29.-30. November 2007 vorgestellt.

Januar—Juni 2008

Aufbauend auf die Inputs beider ExCos als auch der Experten der Task Definition Workshops wurde im Mai 2008 ein erstes Task Definition Papier mit Arbeitsplan erarbeitet. Dieses Papier wurde bei den folgenden ExCo Meeting der beiden Implementing Agreements vorgestellt und in zwei weiteren Runden überarbeitet.

2. Task Definition Meeting, 10.-11. April 2008

Ein zweiter Joint Task Definition Workshop fand am 10.-11. April 2008 bei ECN in Petten, Niederlande statt. An diesem Meeting war das Institut für Wärmetechnik mit Andreas Heinz vertreten. Die Minutes des Meetings finden sich im **Anhang 3.**

3. Task Definition Meeting, 8. Oktober 2008

Im Rahmen der EuroSun 2008 in Lissabon fand ein weiteres vorbereitendes Treffen mit ca. 25 Teilnehmern statt. Österreich war mit dem IWT (Wolfgang Streicher) und AEE INTEC (Alexander Thür) vertreten.

Task Kick-Off Meeting 11.-13. Februar 2009, Bad Tölz, Deutschland

Das offizielle Task Kick-Off Meeting wurde vom 11.-13. Februar 2009 in Bad Tölz, Deutschland abgehalten. Die Tagesordnung dieses Meetings liegt als **Anhang 4** bei, die Minutes waren zum Zeitpunkt dieses Berichts noch nicht verfügbar.

Bei diesem Meeting waren ca. 65 Personen aus 15 Nationen (Australien, Belgien, Dänemark, Deutschland, Frankreich, Großbritannien, Israel, Japan, Niederlande, Österreich, Schweden, Schweiz, Spanien, Türkei, USA) anwesend. Österreich war durch das IWT (Wolfgang Streicher), AEE INTEC (Alexander Thür) und ASIC (Gerald Steinmaurer und Bernhard Zettl) vertreten. Teilnehmende Länder waren Australien, Dänemark, Deutschland, Frankreich, Großbritannien, Israel, Niederlande, Spanien, Österreich, Schweden, Schweiz, Türkei, USA.

Neben der Präsentation der Aktivitäten der Teilnehmer wurden Workshops für die einzelnen Arbeitsgruppen in den Subtasks durchgeführt.

Das IWT (Wolfgang Streicher) wurde als Arbeitsgruppenleiter System Integration im Subtask A Materials eingesetzt.

Task-Experts-Meeting 22.-24. September 2009, Lleida, Spanien

Das zweite Task-Meeting wurde vom 22.-24. September 2009 in Lleida, Spanien mit 71 Teilnehmern abgehalten. Österreich war durch das IWT, (Andreas Heinz), AIT (Daniele Basciotti), ASIC (Bernhard Zettl) vertreten.
Die Tagesordnung dieses Meetings liegt als **Anhang 5** bei. Die Minutes des Meetings wurden für jede Working Group separat erstellt, und wurden aufgrund des relativ großen Umfangs nicht in diesen Bericht inkludiert.

Task Meeting 7.-8. Juli 2010 Bordeaux, Frankreich

Bei diesem Meeting waren 37 Teilnehmer anwesend. Österreich war durch das IWT, (Wolfgang Streicher), AEE INTEC (Dagmar Jähnig), AIT (Daniele Basciotti), ASIC (Bernhard Zettl) vertreten.

Die Tagesordnung dieses Meetings liegt als **Anhang 6** bei. Die Minutes des Meetings wurden für jede Working Group separat erstellt, und wurden aufgrund des relativ großen Umfangs nicht in diesen Bericht inkludiert.

Dritter Semi Annual Staus Report

Halbjährlich werden Berichte des Operating Agent an das IEA SHC Executive Committee übermittelt. Der dritte Semin Annual Status Report vom Juni 2010 liegt als **Anhang 7** bei.

II. Die österreichische Beteiligung am IEA-SHC/ECES Task/Annex 4224

II.1 Zielsetzung des österreichischen Beitrages

Ziel dieser internationalen Kooperation ist die Entwicklung von fortschrittlichen Materialien für kompakte Wärmespeichersysteme für Heizen und Kühlen mit erneuerbaren Energieträgern und zur Energieeinsparung.

Für Österreich bietet sich damit die Chance bestehendes Know-how auf einem äußerst zukunftsträchtigen Gebiet durch die internationale Kooperation weiter auszubauen und bei der Grundlagenforschung zu verbesserten Wärmespeichern an vorderster Front dabei zu sein.

Die österreichischen Teilnehmer arbeiten bei der Task Definition Phase mit und bringen die Erfahrungen des IEA-SHC Task 32 in das Projekt ein. Zudem werden weiterführende Arbeiten im Bereich PCM und Sorption sowie neue Arbeiten im Bereich Sorptionsspeicher in Wärmenetzen durchgeführt.

Insbesondere für das Ziel der deutlichen Steigerung solarer Deckungsgrade in Kombination mit solarthermischen Kollektoren ist die Entwicklung von geeigneten Langzeitwärmespeichern ein wesentliches Ziel.

II.2 Bildung von Team Austria IEA-SHC/ECES Task/Annex 4224

Unter Berücksichtigung der in der Vergangenheit durchgeführten Aktivitäten im Bereich Wärmespeicherung im IEA-SHC Task 32 und anderen Projekten wurden vorerst die folgenden österreichischen Institutionen in das Team Austria aufgenommen:

Institutionen im Antragsteam:

Institut für Wärmetechnik
Technische Universität Graz
Inffeldgasse 25 B, A- 8010 Graz
www.iwt.tugraz.at

AIT
Geschäftsfeld Sustainable Building Technologies
Giefinggasse 2, A-1210 Wien
www.ait.ac.at

AEE INTEC
Institut für Nachhaltige Technologien
Feldgasse 19, A-8200 Gleisdorf
www.aee-intec.at

weitere bisher eingebundene Institutionen (nach Einbindungszeitpunkt):

ASIC ist nicht Partner in der vorliegenden nationalen IEA Projektförderung. Da sich ASIC jedoch ebenfalls mit PCM –Speichern auseinandersetzt, wäre eine Einbindung in Zukunft über eine separate Finanzierung in einem eigenem Projekt oder die Einbindung in ein FollowUp Projekt für die Beteiligung an der weiteren Task-Laufzeit sinnvoll. Hierbei ist eine Gesamtkoordination zwischen allen österreichischen Beteiligten gewünscht.

ASIC Austria Solar Innovation Center
Roseggerstraße
A-4600 Wels
www.asic.at

II.3 Involvierte Personen Team Austria IEA SHC/ECES Task/Annex 4224

Projektleitung und „National Contact Person“:

Ao. Prof. Dr. **Wolfgang Streicher**
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Tel.: +43 (0) 316 873 7306
Fax: +43 (0) 316 873 7305
mail: w.streicher@tugraz.at

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II.4 Arbeitsplan Team Austria IEA-SHC/ECES Task/Annex 4224

Im Sinne der Zielsetzung der österreichischen Beteiligung im Austria IEA SHC/ECES Task/Annex 4224 wurde im Projektantrag ein Arbeitsplan für die Aufteilung der inhaltlichen und organisatorischen Arbeiten aufgestellt. Dieser Arbeitsplan bildet die Grundlage für die Werkverträge zwischen dem Institut für Wärmetechnik und den anderen teilnehmenden Organisationen der Antragsstellung. Es muss jedoch davon ausgegangen werden, dass sich aufgrund wechselnder Projekterfordernisse einzelne Beiträge im Laufe der verbleibenden Laufzeit ändern oder wegfallen bzw. neue Beiträge ergänzt werden können. Inhaltlich werden die folgenden Arbeitsfelder bearbeitet:

1) **Mitarbeit in der Task Definition Phase bei der Erstellung des Workplans und Einbringung der österreichischen Expertise**

2) **Leitung der Arbeitsgruppe „Systems Integration“ des Subtasks A „Materials“**
Definition der Inhalte der Arbeitsgruppe, Entwicklung eines Arbeitsplans und Abstimmung mit den anderen Arbeitsgruppen.

3) **Inhaltliche Arbeiten im Bereich Wärmespeicherung**
IWT und AEE INTEC werden für die in vorhergehenden Tasks (IEA-SHC Task 32) definierte Anwendungssysteme mit fortschrittlichen Speichern unter Verwendung der dort entwickelten Simulationsmodelle für PCM und Sorptionsspeicher als Wärmespeichermedien „ideale“ Materialeigenschaften festlegen, die eine signifikante Verkleinerung des Wärmespeichers bzw. bei gleicher Speichergröße eine Vergrößerung des solaren Deckungsgrades bzw. des Wirkungsgrades der Anwendung, mit sich bringen. Auf diese Weise werden Zielvorgaben für die Suche nach neuen Materialien definiert und mit den theoretischen möglichen Stoffwerten aus der Arbeitsgruppe „Theoretical Limits“ verglichen. Zudem wird an den Entwicklungen von möglichen Speichersystemen für die gefundenen neuen Materialien mitgearbeitet.

In einer zweiten noch zu beantragenden Phase für die weitere Laufzeit des Tasks ist geplant, Erfolg versprechende Wärmespeicher zu entwickeln und in den Labors der beteiligten Institute aufzubauen und zu vermessen, die Simulationsmodelle zu adaptieren bzw. zu verbessern und wiederum Jahressimulationen für Anwendungen mit diesen Speichern im Vergleich zu konventionellen Speichermedien durchzuführen.

AIT wird sich im Rahmen des Tasks mit kompakten Speichertechnologien wie Sorptionsspeicher in Kombination mit Nah- und Fernwärmenetzen beschäftigen. Marktverfügbare Absorptionskältemaschinen sind nur bedingt in Nahwärmenetzen einsetzbar, indem sie wegen der begrenzten Temperaturspreizung auf der Generatorseite die Netzrücklauftemperatur zu sehr erhöhen und daher zusätzliche Kühler im Netz benötigt werden, falls das Netz die Kühlung eines Biogasmotors (zum Beispiel) übernimmt. Die Nutzung von Sorptionsspeichern in einem Nahwärmenetz könnte durch ein optimales Netzmanagement diese negativen Auswirkungen reduzieren, indem die Gleichzeitigkeit von den im Netz auftretenden Lasten gesenkt wird. Als Ergebnis soll eine bessere Ausnutzung der in das Nahwärmenetz eingespeisten Energie erfolgen. Bisher sind Sorptionsspeicher in Kombination mit Fernwärme nur im Rahmen von einzelnen Demonstrationsprojekten untersucht worden. In der hier beantragten Phase sollen Simulationsmodelle von Sorptionsspeichern in ein Nahwärmenetzmodell einfließen. Durch Sensitivitätsanalysen über bestimmte Parameter (Speicherleistung, Anzahl und Positionierung der Sorptionsspeicher im Netz) wird die Einsetzbarkeit von Sorptionsspeichern in Nahwärmenetzen untersucht und die gesamte Netzperformance evaluiert. Eine ausführlichere Systembeschreibung in englischer Sprache ist im Anhang 1 vorhanden.

Weiters wird versucht in Österreich aus anderen Bereichen der Forschung und Industrie Experten und Interessenten zu finden, welche sich in Zukunft aktiv mit dem Thema Wärmespeicherung auseinandersetzen wollen. Dies geschieht im Rahmen nationaler Netzwerke wie NOEST, ASTTP, Solarnet Styria, etc.

Organisation

► 1) Planung und Organisation der österreichischen TASK Aktivitäten
Erstellen von Arbeitsplänen, Abstimmen von Inhalten, Erstellen von Werkverträgen, Unterstützung bei der Ausarbeitung schriftlicher Beiträge, Erstellung eines gemeinsamen Erscheinungsbildes (Layout) für das Team Austria, Kommunikation zu den TASK Gremien. Datenweitergabe von TASK Aktivitäten zu den Mitgliedern des Team Austria und umgekehrt.
INSTITUT FÜR WÄRMETECHNIK

Meetings und Veranstaltungen

► 1) TASK Experts Meeting
Organisation eines Expert Meetings im Rahmen der EuroSun 2010 in Graz: Einladung, Anreise, Unterkünfte, organisatorische Tagesplanung, zwei Besprechungsräume, Präsentationsmittel, Mittagessen, Abendprogramm sind zu organisieren.
INSTITUT FÜR WÄRMETECHNIK und AEE INTEC

► 2) Workshop österreichischer Akteure
Organisation eines Österreich internen Workshops zur Vernetzung relevanter Akteure auf dem Gebiet der thermischen Speicherung. Die Ergebnisse werden zusammengefasst und aufbereitet an die TASK Experten weitergegeben.
AIT und AEE INTEC
Das genaue Thema des Workshops sowie die genaue Zielgruppe sind noch nicht bekannt. Erst wenn die ersten Erkenntnisse aus dem Task vorhanden sein werden, wird entschieden, in welcher Form der Workshop stattfinden soll. Vor allem soll entschieden werden, ob der Workshop im akademischen Bereich bleiben soll oder ob gewisse Ergebnisse schon gegenüber Planern präsentiert werden können.

Die Zeitschrift „erneuerbare energie“ der AEE INTEC (Auflage ca. 5000 Stk) wird für die Verbreitung von Ergebnissen bzw. die Ankündigung von öffentlichen Veranstaltungen/Workshops genutzt.

► 3) Vernetzungstreffen Haus der Zukunft, Transferphase
Teilnahme an den Vernetzungstreffen der Transferphase aus dem Haus der Zukunft. Kurzinformation über die laufenden Aktivitäten im TASK an die Teilnehmer der Transferphase und Übergabe von wesentlichen TASK Ergebnissen.
INSTITUT FÜR WÄRMETECHNIK, AEE INTEC und AIT

II.5 Beschreibung bisheriger Einzelaktivitäten

In der Folge werden die bisher von „Team Austria“ durchgeführten Einzelaktivitäten im Rahmen der Teilnahme am IEA-SHC/ECES Task/Annex 4224 angeführt.

Aktivitäten im Jahr 2007

1. Task Definition Meeting, 5. Oktober 2007
Task Definition Meeting im Anschluss an das IEA-SHC Task 32 Abschlussmeeting
Tagungsort: Zürich
<u>Teilnehmer aus Österreich:</u>
IWT (Wolfgang Streicher) und die AEE-INTEC (Dagmar Jähnig)
Aktivität: Einbringung der Vorstellungen zum Inhalt des neuen Tasks.

Aktivitäten im Jahr 2008

2. Task Definition Meeting, 10.-11. April 2008
Tagungsort: ECN in Petten, Niederlande
<u>Teilnehmer aus Österreich:</u>
IWT (Andreas Heinz)
Aktivität: Einbringung der Vorstellungen zum Inhalt des neuen Tasks.

3. Task Definition Meeting, 8. Oktober 2008
Tagungsort: Lissabon, Portugal, (Side Meeting zur EuroSun 2008)
<u>Teilnehmer aus Österreich:</u>
IWT (Wolfgang Streicher), AEE Intec (Dagmar Jähnig)
Aktivität: Einbringung der Vorstellungen zum Inhalt des neuen Tasks.

4. Österreichisches Kick-Off Meeting 28. Oktober 2008
Das österreichische Kick-Off des Tasks fand am 28. Oktober 2008 am Institut für Wärmetechnik der TU Graz statt. Teilnehmer waren Olivier Pol, Daniele Basciotti (AIT), Dagmar Jähnig (AEE INTEC), Michel Haller, Andreas Heinz, Wolfgang Streicher (IWT). Bei diesem Meeting wurde neben der Information aller Teilnehmer über den Stand des Tasks die Arbeiten der österreichischen Teams im Rahmen des gegenständlichen Projekts fixiert.

Die folgenden Anwendungen sollen von den Teilnehmern primär untersucht werden:
AEE INTEC: Schwerpunkt auf Saisonspeicherung für die Kombination mit solar-

thermischen Anwendungen bzw. Netzeinbindungen.
AIT: Beschränkt auf Anwendungen im Fernwärmebereich, dezentralisierte Kühlung, Lastausgleich und tiefe Rücklauftemperaturen
IWT: derzeit noch nicht klar, möglich sind Kurz- und Langzeitspeicher, solarthermische Anwendungen, Wärmepumpen und Abwärmerückgewinnung.

Numerisch sollen die folgenden Arbeiten durchgeführt werden.

- AEE INTEC, IWT werden ihre Arbeiten im Bereich der Modellierung für PCM- und Sorptionsspeicher ausbauen.
- AIT wird ihr Fernwärmemodell für die Gemeinde Mureck um einen Sorptionsspeicher erweitern. Der Sorptionsspeicher wird als Kühlgerät verwendet (langsames Austrocknen und Nutzen der Kühlenergie). Das Modell wird in DYMOLA aufgesetzt werden. Eventuell ist die Climate Well maschine aus Schweden einsetzbar.

Michel Haller regt an, dass die theoretischen thermodynamischen Grenzen sowohl der Phasenwechselmaterialien und Sorptionsmaterialien als auch der chemischen Speicherprozesse durch Materialwissenschaftler, Festkörperphysiker oder Chemiker ermittelt werden sollten.

Diese und weitere Ergänzungen wurden in den seit Oktober 2008 verfügbaren Draft des Workplans durch die Auftragnehmer eingefügt und haben u.a. dazu geführt, dass eine Arbeitsgruppe „Theoretical Limits“ in den Task aufgenommen wurde.

Aktivitäten im Jahr 2009

5. Task Kick-Off Meeting 11.-13. Februar 2009, Bad Tölz, Deutschland

Das offizielle Task Kick-Off Meeting wurde vom 11.-13. Februar 2009 in Bad Tölz, Deutschland abgehalten. Die Tagesordnung dieses Meetings liegt als **Anhang 4** bei, die Minutes waren zum Zeitpunkt dieses Berichts noch nicht verfügbar.

Teilnehmer aus Österreich:
IWT (Wolfgang Streicher), AEE INTEC (Alexander Thür) und ASIC (Gerald Steinmaurer und Bernhard Zettl)
Aktivität:

- Präsentation der Ergebnisse des IEA-SHC Task 32 im Bereich Phasenwechselmaterialien
- Leitung der Arbeitsgruppe „System Integration“ des Subtask A „Materials“
- Mitarbeit in der Arbeitsgruppe zur Subtask B-Applications in der die anwendungsseitigen Randbedingungen zur technischen Einbindung von Wärmespeichern erhoben und zusammengefasst werden sollen. Input aus der aktiven Beteiligung an den bisherigen bzw. laufenden IEA-SHC Tasks 26 (Solarkombisysteme), 32 (Speicher), 33 (Industrielle Prozesswärme) und 38 (Solares Kühlen).

6. Workshop “Carbon Nano Tubes - Neue Materialien für solarthermische Anwendungen“ 24. März 2009, AEE INTEC, Gleisdorf (in Kooperation mit der austrian Solar Thermal Technology Platform ASTTP)

In Kooperation mit dem “Solarnet Styria” wurde ein Expertenkreis mit Teilnehmern vom NanoTecCenter in Weiz, Technische Universität Graz, Montanuniversität Leoben und der AEE - Institut für Nachhaltige Technologien eingeladen, um die Eigenschaften von „Carbon Nano Tubes“ und ihren möglichen Einsatz in Wärmespeichern zu diskutieren. Es wurde ein weiteres Treffen vereinbart um mögliche zukünftige Kooperationen zu erörtern bzw. vorzubereiten.
Einladungsliste:
Prof. Emil J. W. List, NanoTecCenter Weiz (entschuldigt)

Prof. Christian Slugovc, Technische Universität Graz
DI Helmut Wiedenhofer, NanoTecCenter Weiz
Ao. Univ.-Prof. Wolfgang Streicher, TU Graz, Institut für Wärmetechnik
Univ.-Prof. Reinhold Lang, Montanuniversität Leoben (entschuldigt)
Dr. Gernot Wallner, Montanuniversität Leoben (entschuldigt)
Dr. Erwin Hochreiter, GreenONEtec Solarindustrie
Dr. Alexander Thür, AEE - Institut für Nachhaltige Technologien
D.I. Robert Hausner, AEE - Institut für Nachhaltige Technologien
Dipl.Päd. Ing. Werner Weiß, AEE - Institut für Nachhaltige Technologien
Ing. Ewald Selvicka, AEE - Institut für Nachhaltige Technologien

7. Workshop “Carbon Nano Tubes - Neue Materialien für solarthermische Anwendungen“ 8. Juni 2009, AEE INTEC, Gleisdorf (in Kooperation mit der Austrian Solar Thermal Technology Platform ASTTP)

Fortsetzung des Workshops vom 24.3.2009

Teilnehmer:
Peter Makart, Greenonetec Solarindustrie
Dipl.-Ing. Dr Gernot Wallner, Montanuniversität Leoben
Univ.-Prof. Dr Reinhold Lang, Montanuniversität Leoben
Dipl.-Ing Helmut Wiedenhofer, NanoTecCenter Weiz
Univ.-Prof. Dr. Wolfgang Streicher, TU Graz, IWT
Prof. Emil J. W. List, NanoTecCenter Weiz
Prof. Christian Slugovc, Technische Universität Graz, Institute for Chemistry and Technology of materials (ICTM)
Dr. Bernhard Lamprecht, Institut für Nanostrukturierte Materialien und Photonik, JOANNEUM RESEARCH Forschungsgesellschaft mbH"
Krenn Joachim Dr. "Institut für Nanostrukturierte Materialien und Photonik, JOANNEUM RESEARCH Forschungsgesellschaft mbH"
Wolfgang Reinberger, NanoTecCenter Weiz
Dr. Alexander Thür, AEE - Institut für Nachhaltige Technologien
Ing Christian FinkAEE - Institut für Nachhaltige Technologien
Dipl.Päd. Ing. Werner Weiß, AEE - Institut für Nachhaltige Technologien
Ing. Ewald Selvicka, AEE - Institut für Nachhaltige Technologien

8. Task-Experts-Meeting 22.-24. September 2009, Lleida, Spanien

Das zweite Task-Meeting wurde vom 22.-24. September 2009 in Lleida, Spanien abgehalten. Die Tagesordnung dieses Meetings liegt als **Anhang 5** bei. Die Minutes des Meetings wurden für jede Working Group separat erstellt, und wurden aufgrund des relativ großen Umfangs nur elektronisch in den Bericht aufgenommen.

Teilnehmer aus Österreich:
IWT (Andreas Heinz), ASIC (Bernhard Zettl), AIT (Daniele Basciotti)
Aktivität:

- Leitung der Arbeitsgruppe „System Integration“ WG2C des Subtask C, Vertretung von Wolfgang Streicher als Arbeitsgruppenleiter durch Andreas Heinz
- Mitarbeit in der Arbeitsgruppe zur Subtask B-Applications in der die anwendungsseitigen Randbedingungen zur technischen Einbindung von Wärmespeichern erhoben und zusammengefasst werden sollen. Input aus der aktiven Beteiligung an den bisherigen bzw. laufenden IEA-SHC Tasks 26 (Solarkombisysteme), 32 (Speicher), 33 (Industrielle Prozesswärme) und 38 (Solares Kühlen).
- Präsentation der Koppelung von thermochemischen Speichern und Fernwärmenetzen (Anhang 8)

Aktivitäten im Jahr 2010

9. Task-Experts-Meeting Meeting 7.-8. Juli 2010 Bordeaux, Frankreich

Beim dritten Task-Meeting waren 37 Teilnehmer anwesend. Österreich war durch das IWT, (Wolfgang Streicher), AEE INTEC (Dagmar Jähnig), AIT (Daniele Basciotti), ASIC (Bernhard Zettl) vertreten.

Seitens des IWT wurde u.a. vorgeschlagen für den Vergleich der verschiedenen Speichertechnologien das TRNSYS Modell von IEA-SHC Task 32 zu übernehmen. Hierfür wurde von Wolfgang Streicher eine Präsentationen über dieses Vergleichsverfahren gehalten. Da die meisten Teilnehmer bereits TRNSYS verwenden sollte dies kein Problem darstellen.

AEE INTEC: Dagmar Jähnig, Mitarbeit in der Arbeitsgruppe Space heating and DHW, Teilnahme an den Arbeitsgruppen ‚Materials Engineering and Processing' und‚ Apparatus and Components'

Durchgeführte wissenschaftliche Arbeiten

Institut für Wärmetechnik der TU Graz

Am Institut für Wärmetechnik der TU Graz wurden im Rahmen des Projekts Simulationsrechnungen mit den im IEA-SHC Task 32 definierten Randbedingungen durchgeführt, die das Potenzial einer Integration von Phasenwechselmaterialien (PCM) in den Wärmespeicher eines solaren Kombisystems für Warmwasserbereitung und Heizungsunterstützung aufzeigen sollen. Dabei wurden zunächst unterschiedliche Konfigurationen der Solaranlage hinsichtlich der Kollektorfläche und des Speichervolumens eines Wasserspeichers für ein Gebäude mit einem Heizwärmebedarf von 30 kWh/m^{2}a untersucht. Danach wurden unterschiedliche Varianten einer Einbindung von PCMs in den Wasserspeicher für die einzelnen Konfigurationen getestet. Dabei wurden verschiedene Parameter – wie z.B. die Schmelzenthalpie des PCM oder der Volumenanteil an PCM im Speicher – variiert.

Die Ergebnisse zeigen, dass der solare Deckungsgrad, bzw. der spez. Solarertrag der Solaranlage durch die Integration eines gängigen PCM in den Speicher gegenüber einem konventionellen Wasserspeicher verbessert werden kann. Diese Verbesserung ist bei Systemen mit hohen solaren Deckungsgraden, die in Richtung saisonale Wärmespeicherung tendieren, viel stärker ausgeprägt als bei Konfigurationen mit einem niedrigen Deckungsgrad. Die Simulationen ergeben, dass eine solare Volldeckung des Wärmebedarfs mit einem PCM-Speicher bereits mit einem wesentlich kleineren Speichervolumen erreichbar ist als mit einem Wasserspeicher.

Zusätzliche Berechnungen, die eine Verdoppelung der Schmelzwärme des eingesetzten PCM berücksichtigen, zeigen, dass durch ein Material mit einer derart verbesserten Speicherkapazität eine weitere wesentliche Reduktion des notwendigen Speichervolumens möglich wäre.

Im Anhang 9 befindet sich eine Veröffentlichung bei der EuroSun 2010, die detailliertere Informationen zu diesen Arbeiten enthält.

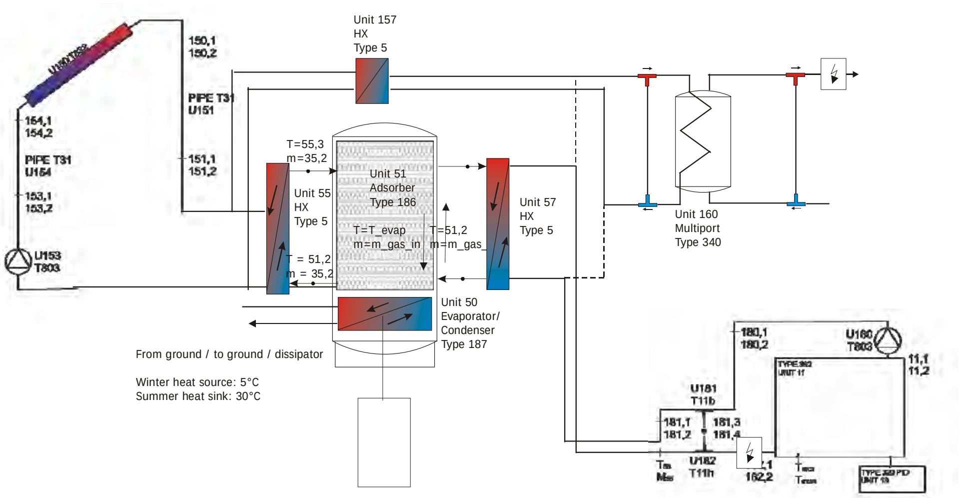
AEE INTEC

Im Rahmen des vorhergehenden Task 32 (Advanced Storage Concepts for Solar and Low Energy Buildings) wurde von der AEE INTEC ein Simulationsmodell erstellt, mit dem unter den im Rahmen des Tasks definierten Randbedingungen ein System zur solaren Heizung und Warmwasserbereitung mit einem geschlossenen Sorptionsspeicher simuliert werden konnte. Dieses Simulationsmodell besteht aus einer einfachen Massen- und Energiebilanz, über die die Transportvorgänge bei der De- und Adsorption in einem Sorptionsspeicher dargestellt werden können.

Bei einem damals von der AEE INTEC durchgeführten Demonstrationsprojekt wurde dazu das Materialpaar Silikagel – Wasser verwendet. Da der zu erreichende Temperaturhub bei dieser Paarung relativ gering ist, wurde ein System konzipiert, bei dem nur die Raumheizung vom Sorptionsspeicher versorgt und die Warmwasserbereitung allein von Solarenergie und Nachheizenergie gedeckt wurde. Auf diese Weise ist allerdings die solare Deckung für Heizung UND Warmwasserbereitung immer nach oben begrenzt.

Im neuen Task 4224 sollen jetzt neue Wärmespeichermedien entwickelt werden, mit denen eine nahezu 100%ige Deckung des Wärmebedarfs für Heizung und Warmwasser in einem Niedrigenergiehaus möglich ist. Eine Simulation mit „fiktiven“ Materialeigenschaften von Sorptionsmaterialien soll dazu führen ideale Materialeigenschaften für diese Anwendung zu definieren, mit denen dieses Ziel erreicht werden kann. Diese Kenndaten werden dann einerseits mit den theoretisch möglichen Stoffwerten aus der Arbeitsgruppe „Theoretical Limits“ verglichen, andererseits dienen sie als Basis für die Entwicklung von Materialien zur Wärmespeicherung, die von den Materialforschungsinstituten in diesem Task durchgeführt wird.

Im ersten Schritt wurde dazu von der AEE INTEC das aus der Task 32 vorhandene Simulationsmodell so umgebaut, dass sowohl Heizung als auch Warmwasserbereitung über den Sorptionsspeicher gedeckt werden können und der konventionelle Pufferspeicher (Wasser), der im Modell für die Task 32 noch enthalten war, entfallen kann.



Da Sorptionsmaterialien typischerweise poröse Materialien sind, ist die Wärmeleitfähigkeit üblicherweise relativ gering. Daher ist es nur schwer möglich die Warmwasserbereitung direkt aus dem Sorptionsspeicher heraus zu gewährleisten. Daher wurde im Konzept für die Simulationen ein kleiner separater Warmwasserspeicher vorgesehen, der dann sowohl direkt von der Solaranlage als auch vom Sorptionsspeicher (z.B. in einem Zeitfenster nachts) beladen werden kann.

In der Abbildung ist das in der Simulation realisierte Systemschema dargestellt.

Die Regelung eines solchen Systems erweist sich allerdings als durchaus komplex. Insbesonders ist hier die Regelung der Solaranlage problematisch, die wechselweise den großen Sorptionsspeicher und den wesentlich kleineren Warmwasserspeicher beladen soll oder ggf. beide gleichzeitig. Schwierig sind hier die unterschiedlichen Volumenströme und auch ggf. die unterschiedlichen Temperaturen. Der Sorptionsspeicher kann und soll je nach verwendetem Sorptionsmaterial auch bei Temperaturen deutlich über 100°C betrieben werden (dies ist mit Vakuumröhrenkollektoren auch ohne Probleme möglich), der Warmwasserspeicher dagegen darf nur bei Temperaturen betrieben werden, bei denen das Wasser nicht verdampft. Idealerweise sollte die Temperatur sogar unter 60°C bleiben, um Verkalkung des Speichers zu verhindern. Dies ist nicht nur in der Realität sondern auch in der Modellierung ein Problem, da der Speicher in einzelnen Segmenten berechnet wird, und ein solches Segment bei gleichzeitig hohem Volumenstrom aufgrund der großen Kollektorfläche, die wesentlich größer ist als bei einer reinen Warmwassersolaranlage, schnell Temperaturen erreichen kann, bei denen das Wasser verdampft.

Das Simulationsmodell ist zum Großteil aufgebaut und lauffähig. Durch die oben beschriebenen Probleme mit der Solarregelung liegen aber noch keine Ergebnisse vor und es konnten auch nicht – wie geplant – schon Ergebnisse beim Experts Meeting in Bordeaux (Juli 2010) präsentiert werden. Es ist geplant, das Simulationsmodell in den nächsten Monaten fertigzustellen und die Ergebnisse dann bei einem Experts Meeting vorzustellen.

Im weiteren Verlauf des Tasks ist geplant, das Simulationsmodell mit Materialkenndaten von im Rahmen des Tasks neu entwickelten Materialien laufen zu lassen und somit das Potential der neuen Materialien für diese Anwendung (saisonale Speicherung von Solarwärme für Raumheizung und Warmwasserbereitung in einem Niedrigenergie-Einfamilienhaus) abschätzen zu können.

AIT

Das AIT erstellte einen Bericht über die Möglichkeiten des Einsatzes von Thermochemischen Speichern in Nahwärmenetzen in Kombination mit Absorptionskältemaschinen oder Desiccant Cooling Systeme (DEC). Nach einer ausführlichen Recherche der vorhanden Technologien und der vorhanden Simulationsmodelle von thermochemischen Speichern wurde eine Simulation der Wärmenetze mit diesen Komponenten durchgeführt. Der vollständige Bericht ist als **Anhang 10** beigefügt.

III. Anhänge

Anhang 1: Revised Workplan, May 2009

Anhang 2: Minutes des 1. Task Definition Meeting, Zürich, Oktober 2007

Anhang 3: Minutes des 2. Task Definition Meeting, Petten, 10.-11. April 2008

Anhang 4: Tagesordnung zum Kick-Off Meeting in Bad Tölz, 11.-13. März 2009

Anhang 5: Tagesordnung zum 2. experts Meeting in Lleida, Spanien 22.-24. September 2009

Anhang 6: Tagesordnung zum 3. experts Meeting in Bordeaux, Frankreich, 7.-8. Juli 2010

Anhang 7: Third Semi Annual Status Report, IEA-SHC/ECES Task/Annex 4224

Anhang 8: Präsentation Basciotti (AIT), Why Thermochemical Storage for District heating, Lleida Meeting

Anhang 9: Präsentation Heinz (IWT), Simulation results of PCM Seasonal storage, Bordeaux Meeting

Anhang 10: Bericht des AIT über die Koppelung von thermochemischen Speichern mit Nahwärmenetzen.

Anhang 1: Revised Workplan, May 2009

Task 42 **Annex 24**

Compact Thermal Energy Storage: Material Development for System Integration

Revised Work Plan
May 2009

Compact Thermal Energy Storage:
Material Development for System Integration

Introduction

More than half of our primary energy resources are used to generate heat. Therefore, technologies for increasing the share of sustainable heat sources and for improving the efficiency of thermal systems are of key importance.

Thermal energy storage technologies are needed for both: to match the intermittent supply of sustainable heat and to optimise the thermal system performance. Present thermal energy storage technologies, based on water, perform well, but on a relatively low level of efficiency, particularly for long-term storage. These systems can only be improved marginally; new materials and systems are needed to enable a breakthrough. From past IEA SHC and ECES Tasks/Annexes it was concluded that broad and basic research and development initiative is needed to find and improve compact thermal energy storage materials. The IEA joint Task/Annex 42/24 will bring together experts from both the materials development field and the systems integration fields. In four years, the task aims at having finished the first steps towards a new generation of thermal storage technologies.

1 Objectives and Scope

1.1.1 Objective

The overall objective of this task is to develop advanced materials and systems for the compact storage of thermal energy. This can be subdivided into eight specific objectives:

- to identify material requirements for relevant applications, by means of numerical simulation of currently known storage technologies, using the simulation modules developed e.g. in IEA SHC Task 32.
- to identify, design and develop new materials and composites for compact thermal energy storage,
- to develop measuring and testing procedures to characterise new storage materials reliably and reproducibly,
- to improve the performance, stability, and cost-effectiveness of new storage materials,
- to develop multi-scale numerical models, describing and predicting the performance of new materials in thermal storage systems, and to compare them to conventional storage systems,
- to develop and demonstrate novel compact thermal energy storage systems employing the advanced materials,
- to assess the impact of new materials on the performance of thermal energy storage in the different applications considered, and
- to disseminate the knowledge and experience acquired in this task.

A secondary objective of this task is to create an active and effective research network in which researchers and industry working in the field of thermal energy storage can collaborate.

1.1.2 Scope

This task deals with advanced materials for latent and chemical thermal energy storage, and excludes materials related to sensible heat storage. However, the latter category is used as reference. The task deals with these materials on three different scales:

- material scale, focused on the behaviour of materials from the molecular to the ‘few particles’ scale, including e.g. material synthesis, micro-scale mass transport, and sorption reactions;
- bulk scale, focused on bulk behaviour of materials and the performance of the storage in itself, including e.g. heat, mass, and vapour transport, wall-wall and wall-material interactions, and reactor design;
- system scale, focused on the performance of a storage within a heating or cooling system, including e.g. economical feasibility studies, case studies, and system tests.

Because seasonal storage of solar heat for solar assisted heating of buildings is the main focus of the IEA-SHC IA, this will be one of the primary topics of this task.

However, because there are many more relevant applications for TES, and because materials research is not and can not be limited to one application only, this task will include multiple application areas, bundled into three application working groups.
Applications that will be included from the start of this task are:

Low temperature (up to 20 ºC):
- building cooling
- refrigeration

Medium temperature for room heating and hot tap water (20 ºC – 100 ºC):
- seasonal solar thermal storage
- cogeneration, trigeneration and heat pumps

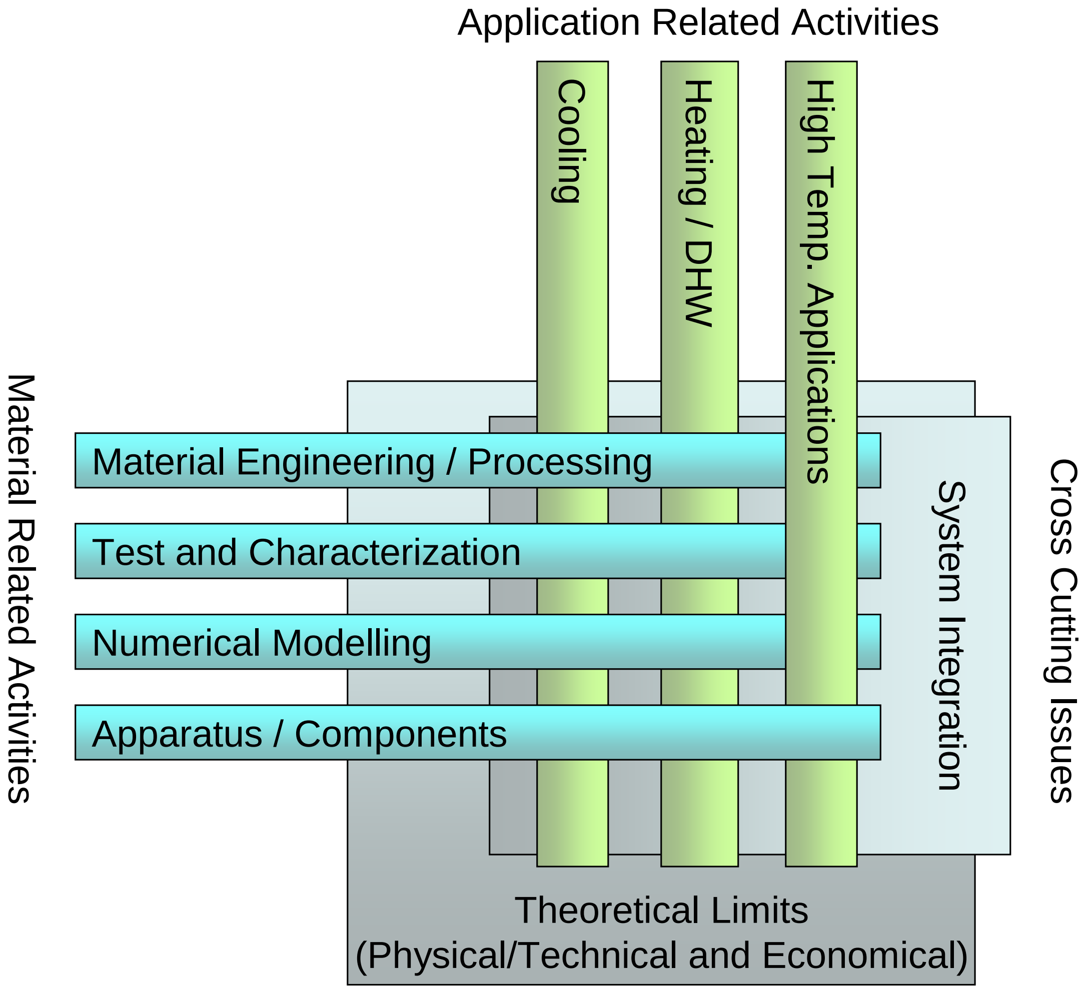
Higher temperatures (100 ºC and above):
- district heating
- industrial waste heat
- concentrated solar power

This subdivision enables the addition of new interesting applications. If, during the task's four-year operation, new promising applications are revealed, they can be included in the task's scope at a later point. Vice versa, if the interests in one of the above-mentioned applications fade, it can be decided to drop this particular application as a focus point of the task. The organisation of the task allows for this flexibility.
Three additional working groups will focus on common tasks: dissemination, system integration and theoretical limits (see section 3.3).

2 Organisation

2.1 Organisational structure

The Task is organised in a matrix-like structure (see diagram below): such a structure (1) maximises the interaction between materials researchers and application experts, (2) maximises knowledge exchange between groups working on adjacent topics, and (3) gives the task an organisational structure that reflects the different emphasis, backgrounds, and working cultures of the two Implementing Agreements in this Joint Task.



One axis represents materials-related activities. It is divided into groups of similar activities:

- Materials engineering and processing,
- Tests and characterisation,
- Numerical modelling
- Apparatus and components

The other axis represents application-related activities, and is grouped into application categories. The categories are following the usable temperature range of thermal energy delivered by the storage systems:

- Cooling (about 0°C – 20 °C, or colder)
- Heating / Domestic Hot Water (about 20 °C – 100 °C)
- High Temperature Applications (> 100 °C)

Each axis corresponds to a Subtask, and each category corresponds to a Working Group. Each of the two subtasks is coordinated by one of the two Operating Agents: Andreas Hauer, Operating Agent on behalf of ECES, coordinates Subtask A on materials, and Wim van Helden, Operating Agent on behalf of SHC, coordinates Subtask B on applications. Each Working Group is coordinated by a Working Group Leader.

In addition to the Material and Application group two Working groups concerning cross-cutting issues were installed:

- System integration
- Theoretical limits

These working groups are dealing with questions of general interest and importance.

At the first Task/Annex meeting in February 2009 the following working group leaders were assigned:

Materials:

Material Engineering / Processing	WG Leader: Royal Institute of Technology KTH, Stockholm, Sweden (Victoria Martin), TREFLE / CNRS, Bordeaux, France (Elena Palomo)
Test and Characterization	WG Leader: Institute for Solar Energy Technologies, Freiburg, Germany (Stefan Gschwander)
Numerical Modelling	WG Leader: Eindhoven University of Technology, Eindhoven, The Netherlands (Camilo Rindt)
Apparatus / Components	Ad Interim WG Leader: Energy research Centre of the Netherlands ECN (Wim van Helden).

Applications:

Cooling	WG Leader: Cukurova University, Adana, Turkey (Halime Paksoy)
Heating / DHW	WG Leader: National Laboratory on Renewable Energies, Golden, Colorado, USA (Jane Davidson)

High Temp. Applications	WG Leader: University Lleida, Lleida, Spain (Luisa Cabeza)

Cross Cutting:

Theoretical Limits	WG Leader: Bavarian Center for Applied Energy Research, Garching, Germany (Eberhard Lävemann)
System Integration	WG Leader: Technical University Graz, Graz, Austria (Wolfgang Streicher)

The activities in each Working Group are described in more detail in section 3.

2.2 Meetings

Every six months, a Task Meeting will be organised. To distribute the cost and work load of meeting organisation as evenly possible, every Task Meeting, eight in total, will be organised by a different task participant.

Because the most fundamental objective of this Task is to exchange knowledge and experience between experts from widely varying backgrounds, as a first principle all Task Meetings should be kept plenary. Since the first meeting had almost 80 participants, some parts of the Task meetings will have to be split up into parallel sessions. Future meetings should have this general structure:

2-Days-Meeting + Technical Tour

1. Day:
- Meeting of Working Group Leaders and Operating Agents (Reports on activities in the Working groups, agendas for WG meetings in parallel sessions)
- Parallel Sessions on “Materials”:
    - Material Engineering / Processing
    - Test and Characterization
    - Numerical Modelling
    - Apparatus / Components

2. Day
- Parallel Sessions on “Applications”:
    - Cooling (0 °C – 25 °C)
    - Heating / DHW (25 °C – 100°C)
    - High Temp.Appl. (> 100 °C)
- Parallel Sessions on“Cross Cutting”:
    - Theoretical Limits
    - System Integration
- Plenary Session: Summaries from the Working Groups

3. Day:
- Technical Tour

2.3 Status reports

In addition to the deliverables in report-form, a semi-annual status report will be provided to both ExCos. The Operating Agents are responsible for the writing of these reports; however, they will have to rely strongly on the contribution of their Working Group Leaders. Each Working Group Leader is expected to describe the progress in his Working Group during the last half year. The Operating Agents will compile these contributions into an overall status report, and add a section on the overall operational progress of the Task. The Operating Agents will also describe the Task's dissemination activities and the activities progress regarding the 'soft' Task objectives, e.g. the establishment of an effective international research network.

3 Activities

3.1 Subtask A Materials

3.1.1 Working Group A1 Materials Engineering/Processing

Engineering

The activities in this Working Group focus on engineering new materials or composites, i.e. changing the properties of existing materials and developing new materials with better performance, lower cost, and improved stability. Eventually, this should lead to the ability to design new materials tailor-made to specification. The materials under consideration are those relevant to thermal energy storage using sensible mode, phase change, as well as chemical reactions and sorption technologies. This Working Group includes the following activities:

- synthesis of new materials;
- determination of material characteristics such as phase diagrams;
- determination of the relation between material performance and material structure and composition, in order to direct the search for improved materials;
- create material safety data sheets;
- determination of the role and importance of material containers.

Deliverables

#	Deliverable	Month
A1.1	Material database: a) PCM materials; and b) sorption materials; and c) assessment of chemical reactions	12
A1.2	Samples of new materials for material testing	24
A1.3	Material safety data sheets	36

Processing

The activities in this Working Group focus on the processing of raw materials that is required to make these materials function in a realistic environment. In nearly all cases, storage material can not be used to store heat in its raw form, but e.g. needs to be processed into a slurry, encapsulated, or otherwise processed.

The following activities in the Processing area are included:

- finding optimal methods for micro- and macro encapsulation of storage materials (particularly phase change, sorption, and thermochemical materials);
- processing of phase-change slurries;
- finding new combinations of materials.

Deliverables

#	Deliverable	Month
A1.4	Inventory of production technologies	24
A1.5	Material price data sheets	36

3.1.2 Working Group A2 Tests and Characterisation

The performance characteristics of novel thermal energy storage materials, like phase-change materials or thermochemical materials, often cannot be determined as straightforward as with sensible heat storage materials. In order to have proper comparison possibilities appropriate testing and characterisation procedures should be developed and assessed.

The activities of this Working Group are aimed at developing these new procedures and include:

- comparative testing of materials and their required methods;
- long-term stability determination;
- (pre-)standardisation of testing methods.

Deliverables

#	Deliverable	Month
A2.1	Analysis of comparative testing methods	24
A2.2	Long-term stability test protocols for several classes of materials	48

3.1.3 Working Group A3 Numerical Modelling

The activities in this working group are aimed at developing and testing numerical models that help to understand and optimise the material behaviour and the dynamic behaviour of compact thermal energy storage systems and components. Ultimately, these numerical models could help to find ways to optimise the materials in combination with the system components. The activities in this working group help to lay the foundation for such models.

The Working Group includes the following activities:

- Micro-scale modeling
- Meso-scale modeling
- Macro-scale modeling
- Multi-scale approach
- Thermo-mechanical modeling
- Reactor models

Deliverables

#	Deliverable	Month
A3.1	Report on state-of-the-art modeling techniques of TCM/PCM-materials on micro-, meso- and macro scales	12
A3.2	Collection of experimental data on the behavior of TCM/PCM-materials which can be used to bench-mark numerical codes	18
A3.3	Progress report on the (validated) numerical models developed for the micro-, meso-, macro and multi-scale	30
A3.4	Overview of material properties required for increased storage performance compared to conventional storage techniques	48
A3.5	Final report on the (validated) numerical models developed for the micro-, meso-, macro and multi-scale	48

3.1.4 Working Group A4 Apparatus / Components

The storage apparatus is composed of the storage material and the equipment necessary to charge and discharge the storage material in a controlled and optimal way. This includes heat and mass transfer equipment like heat exchangers and pumps or fans and (chemical) reactors. Methods for the design and optimisation of components and apparatus should be developed, together with appropriate testing methods and procedures to assess the long-term behaviour of an apparatus.

This Working Group includes the following activities:

- storage container and reactor design;
- storage apparatus design, based on the selected storage materials;
- improve heat transfer from material to reactor wall or heat exchanger wall;
- apparatus performance assessment;
- assessment of durability of components;
- develop and apply test and validation methods for storages.

Deliverables

#	Deliverable	Month
A4.1	First version of reactor design methodology	24
A4.2	Storage apparatus performance test protocols	36
A4.3	Long-term apparatus durability test protocols	36

3.2 Subtask B Applications

There are several applications for compact thermal energy storage technologies, each with a different set of boundary conditions for the technology. Although the applications themselves place very different requirements on storage technology, the steps that must be taken are very similar for all applications. Hence, the activities within the Working Groups in this Subtask are very similar as well.

The activities in these Working Groups serve the underlying guidance principle of the materials development within the limitations of the application. The materials development will be directed by the desired system performance. A constant assessment of performance criteria for a given application will be used to determine the chances for a given material/system combination. These criteria can come from economic, environmental, production technology or market considerations.

Activities in the Application Working Groups include:

- definition of application boundary conditions, such as load, demand, environment, dimensions, etc.;
- definition of required thermophysical properties for each application;
- selection of relevant candidate materials and system technologies;
- performance assessment and validation;
- numerical modelling on the application level;
- case studies;
- economical modelling;
- feasibility studies;
- market potential evaluations.

This subtask is subdivided in Working Groups, each representing a particular application or group of similar applications. This subdivision will be kept flexible throughout the Task, to allow for new research groups and projects to join and include new topics at a later point in the Task. This flexibility allows the Operating Agents of the Task to adjust the organisation of the task activities and the meetings as the work progresses. The flexible subdivision also allows for a reshuffling of projects and groups—if needed—during the Task with the intention to maximise cross-fertilisation and knowledge exchange between participants.

Based on the current participants and feedback on the Task organisation, the Task will start with the following Working Groups:

- Working Group B1: Cooling
- Working Group B2: Heating / DHW
- Working Group B3: High Temperature Applications

Deliverables

#	Deliverable	Month
Bx.1	Boundary conditions and requirements for each application	12
Bx.2	Case studies for several applications	24
Bx.3	Techno-economical potential for each application	36
Bx.4	Numerical system model for each application	42
Bx.5	Upper performance limit estimation for each application	48
Bx.6	Lab-scale tests of several applications	36
Bx.7	Field test of at least one application	48
Bx.8	Life-cycle cost analysis for several applications	48

3.3 Common Tasks

3.3.1 Dissemination

One of the objectives of this Task/Annex is to inform the different groups of stakeholders in the development of compact thermal storage of the Task’s progress and planned activities. These stakeholders include researchers, industry representatives, and policy makers. This common Task plays a major role in reaching the secondary objective of the Task, i.e. the creation of an effective international network for research and development of compact thermal energy storage.

Dissemination will be performed through the following channels:

- scientific papers,
- conference contributions,
- articles in professional journals and magazines,
- newsletters,
- contribution to scientific and non-scientific events related to thermal storage.

This activity will be supervised by the Operating Agents.

3.3.2 Working Group C1 Theoretical Limits

The objective of this Working Group is to determine the theoretical limits of compact thermal storage materials and systems from a physical, technical and economical viewpoint. In short, this Working Group defines the maximum possible performance that can be expected from a thermal storage system in a given application. As such, it gives a reference point with which the performance of lab tests, field tests, and real-life systems can be compared. In a first step physical limits shall be determined, e.g. the energy stored per volume and per mass as a function of temperature, with respect to different mechanisms as sensible, latent, sorption or chemical storage. In a second step technical aspects shall be evaluated. In many cases the energy storage density and the efficiency of the system are deteriorated when a large specific thermal power must be drawn from the system. In a third step economical constraints of storage systems shall be evaluated.

Deliverables

#	Deliverable	Month
C1.1	Physical limits of thermal energy storage density as a function of temperature	12
C1.2	Technical limits and constraints	24
C1.3	Economical limits and constraints	36

3.3.3 Working Group C2 System Integration

The storage apparatus is part of a larger thermal system. Next to the apparatus, the thermal energy supply, the control, the thermal transport components and the thermal energy user are elements of the thermal system. Methods for the design and optimisation of components and systems should be developed, together with appropriate testing methods and procedures to assess the long-term behaviour of a system.

This Working Group includes the following activities:

- inventory and analysis of existing store types, their theoretical and practical energy and power density, their possible application and their costs (if available) following the results of IEA SHC Task 32 and IEA-ECES Tasks;
- storage system design, based on the selected storage materials (link to A2) and applications;
- system performance assessment for various applications;
- assessment of durability of components;
- develop and apply test and validation methods for storages (starting with the existing test methods for hot water stores).

Deliverables

#	Deliverable	Month
C2.1	Inventory and analysis of existing store types and their possible applications	12
C2.2	First version of storage system design methodology	24
C2.3	Storage system performance test protocols	36

3.4 Timetable

	2009				2010				2011				2012			
Working Group	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
A1 Materials engineering and processing				A1.1				A1.2 A1.4				A1.3 A1.5				
A2 Tests and characterisation								A2.1								A2.2
A3 Numerical modelling				A3.1		A3.2				A3.3						A3.4 A3.5
A4 Apparatus and Components								A4.1				A4.2 A4.3				
Bx Applications				Bx.1				Bx.2				Bx.3 Bx.6		Bx.4		Bx.5 Bx.7 Bx.8
C1 Theoretical limits				C1.1				C1.2				C1.3				
C2 System integration				C2.1				C2.2				C2.3				
Task meetings	●		●		●		●		●		●		●		●	

4 Participants

The status of participation in the Task as of May 2009 is presented in the table below.

					Person-months	
Country	**Organisation**	**Responsible**	**Funding status**	**IA**	**Project**	**Task**
AT	IWT/AEE/Arsenal	Wolfgang Streicher	funded	SHC	24	6
AT	ASIC	Bernhard Zettl	funding applied for			
AU	University of South Australia	Frank Bruno	funding applied for	SHC		
BE	VITO	Johan van Bael	funding applied for	ECES		
CH	EMPA	Robert Weber	funded until 2010	SHC	12	2
CH	SPF	Elimar Frank	funding applied for	SHC		
DE	Univ. Erlangen	Jimmy Ofili	funding applied for	ECES		
DE	Fraunhofer ISE	Peter Schossig	funded	ECES		
DE	Fraunhofer UMSICHT	Clemens Pollerberg	no funding	ECES		
DE	ITW Stuttgart	Henner Kerskes	funded	ECES	100	6
DE	University of Kassel	Roland Heinzen	funded	ECES	48	4
DE	University of Magdeburg	Franziska Scheffler	funding applied for			
DE	Univ. Luneburg	Oliver Opel	funding applied for	ECES		
DE	Vaillant	Max Bankowski	funded	ECES		
DE	ZAE Bayern	Andreas Hauer	funded	ECES	24	12
DK	DTU	Simon Furbo	funded	SHC	15,6	
ES	Abengoa Solar	Cristina Prieto	funding applied for	SHC		
ES	CIEMAT	Rocio Bayon	funded	SHC	56	
ES	Inasmet	Patricio Aguirre	funding applied for	SHC		
ES	Tekniker	Miren Blanco	funded	SHC		
ES	University of Lleida	Lluisa Cabeza	funded	ECES		
ES	University of Zaragoza	Ana Lázaro	funded	SHC	19,7	1,15
FI	VTT	Lisa Wikstrom	funding not sure	SHC		
FR	CSTB	Peter Riederer	funding applied for			
FR	EDF	Philippe Stevens	funded		48	8
FR	INES	Philippe Papillon	funded			
FR	Université de Bordeaux	Elena Palomo	funded			
FR	Université de Lyon	Frédéric Kuznik	funded			
FR	Université de Savoie	Lingai Luo	funded		40	2
NL	Capzo	Herman Reezigt	funding not sure	SHC		
NL	ECN	Martijn van Essen	funded	SHC	48	24
NL	Eindhoven Univ. of Technology	Camilo Rindt	funded	SHC	52	
SE	Ecostorage/KTH	Viktoria Martin	funded	ECES	48	8
SI	National Institute of Chemistry	Venceslav Kaucic	funding applied for			
TR	Cukurova University	Halime Paksoy	funding applied for	ECES		
UK	BASF	Kishor Mistry	funded		16	
UK	University of Loughborough	Philip Eames	funding applied for			
UK	University of Warwick	Chang-Ying Zhao	funded		100	
US	Oak Ridge National Laboratory	Jan Kosny	funded	SHC		
US	University of Minnesota	Jane Davidson	funded	SHC		
			Total		**651,3**	**73,15**

Anhang 2:

Minutes des 1. Task Definition Meeting, Zürich, Oktober 2007

New IEA Task: “Advanced materials for thermal energy storage”

Expert meeting, Zürich (CH), 5 October 2007

Minutes

After a brief welcome and introduction, the proposal for a new IEA task on advanced materials for compact thermal energy storage is presented and discussed with all meeting participants. In addition, an introduction round is made, in which everyone introduces themselves and their organisation, and explains their interest in the new task.

The presentation, containing an overview of the proposed task’s objectives, scope, and organisation, is attached separately. In the following, the discussion and remarks have been summarised and organised by topic.

Background and motivation of the task

In addition to the tasks mentioned in the presentation (SHC 32, ECES 17), IEA ECES Annex 10 also concluded that more research on materials is necessary. IEA ECES Annexes 18 and 19 come to the same conclusion.

A general trend is visible—not only in solar—where research has moved from materials to systems and back again to materials. It has become clear that the existing materials cannot be used directly in systems, but that these materials need to be improved themselves first.

Scope

Thermal energy storage is relevant for many fields: not only for renewable energy (including solar), but also for energy conservation. Therefore, it is important not to limit the task to one application (e.g. solar), but to broaden our view to more applications. (See also *Collaboration*).

On the other hand, some boundaries help to prevent the task from losing coherence. It is impossible to work on materials without having some kind of application in mind, and having some kind of reference application helps to define clear goals, e.g. in terms of increased system efficiency for the selected applications.

After some discussion, the preferred approach is to select a few key applications as focal points for the task work, but to keep the task open for materials research in a broader sense. These key applications can be defined in terms of technologies (e.g. seasonal solar storage or micro-CHP peak shaving), but also in terms of operating conditions (e.g. temperature, pressure, and storage time limits).

It must be made clear in the definition of the task that *thermal energy storage* includes both heat and cold storage. Moreover, the environmental impact of materials should be kept in mind, so that the task is not only limited to an energetic optimisation.

Industry participation

The industry representatives at the meeting point out that thermal energy storage is not a niche, but a very important field. Several industries already have their own developments that are very relevant to the task. Finding applications is of paramount importance for industry.

Collaboration

The introduction round has shown that there are roughly two types of fields of interest for this task: applications/systems and materials. The main aim of this task is to bring material researchers and systems experts together. This is very beneficial for both: it gives materials researchers a clearer view on applications for their work, and gives system experts more knowledge of materials to improve their systems with.

Thermal energy storage is an important part in many renewable energy systems as well as in many energy conservation technologies. This is both a blessing and a curse: simply put, everybody agrees that storage is important, but nobody feels primarily responsible. This becomes clear when considering in which Implementing Agreement this task fits best: a task on storage materials could be placed under many different IAs.

After some discussion, it is preferred to place this task within the Solar Heating and Cooling Implementing Agreement, while actively cooperating with other IAs: in particular with Energy Conservation through Energy Storage, but also with SolarPACES, District Heating and Cooling, Heat Pumping Technologies, Energy Conservation in Community and Building Systems, Industrial Energy-related Technologies and Systems, and Renewable Energy Technology Deployment.

Task organisation

It is agreed to organise the task in a matrix structure, with activity areas on one axis (materials analysis, modelling, system studies, etc.) and application areas on the other. This structure improves the chances for cross-fertilisation amongst the task participants.

Follow-up

The discussion and remarks during the meeting will be used in the preparation of a first draft proposal for the new task. This will be sent around to all meeting participants for further feedback. This draft will be proposed to the IEA SHC ExCo at their next meeting on 5–7 December 2007, and will be sent to the ExCos of other relevant IAs for their input and suggestions.

Meeting participants

Name	Organisation	Country
Marco Bakker	ECN	NL
Chris Bales	SERC	SE
Max Bankowski	Vaillant Group	DE
Jacques Bony	HEIG-VD	CH
Luisa Cabeza	University of Lleida	SP
Viktor Dorer	EMPA	CH
Philip Eames	University of Warwick	UK
Martijn van Essen	ECN	NL
Elimar Frank	SPF	CH
Paul Gantenbein	SPF	CH
Dietmar Gross	ISFH	DE
Jean-Christophe Hadorn	Base Consultants	CH
Zeming He	University of Eindhoven	NL
Wim van Helden	ECN	NL
Jin Hu	HEIG-VD	CH
Dagmar Jähnig	AEE Intec	AT
Henner Kerskes	ITW	DE
Thomas Letz	INES	FR
Kishor Mistry	Ciba Specialty Chemicals	UK
Lucienne Krosse	TNO	NL
Volkmar Lottner	Former IEA ExCo for ECES and SHC	DE
Javier Gravalos Moreno	Acciona Infraestructuras	SP
Tomas Nuñez	Fraunhofer ISE	DE
Franziska Scheffler	ZAE Erlangen	DE
Philippe Stevens	EDF	FR
Wolfgang Streicher	University of Graz	AT
Robert Weber	EMPA	CH
Urs Wolfer	Swiss Energy Office	CH
Katrin Zass	University of Kassel	DE

Anhang 3:

Minutes des 2. Task Definition Meeting,

Petten, 10.-11. April 2008

IEA SHC/ECES Joint Task on

Compact Thermal Energy Storage:
Material Development and System Integration

Minutes of the Task Definition Meeting
ECN, Petten, the Netherlands, 10–11 April 2008

Day 1

9.00 Welcome and introduction, Wim van Helden

See presentation. The discussion during and after the presentation is noted here.

When asked how we intend to manage potential problems in having two Executive Committees (ExCos) managed, Wim van Helden explains that there will be one line of reports for both ExCos, with each ExCo focusing on different aspects of the task. The ECES ExCo will focus on the material-related aspects in the task, while the SHC ExCo will focus on the application-related aspects. However, it is stressed that both Implementing Agreements already have a much broader view—the activities within ECES already includes work on applications, while the activities within SHC already include some materials research.
To prevent the possibility that both ExCos, coming from different backgrounds, will judge the task's performance in different ways, the communication between the Operating Agents (OAs) and both ExCos must be very open. First of all, the two (proposed) OAs are already cooperating very closely during the task. In addition, a Steering Committee will be formed, consisting of two ExCo members from both Implementing Agreements (IAs), which has the specific objective to discuss any potential differences in view between the two ExCos.

It is agreed that economics is an important issue that needs to be explicitly included in the work. Having a good material is not worthwhile if it is too expensive; on the other hand, a cheaper version of the same material could be very valuable for another application. Because of economics, it is also very important to include work on production technologies, since this greatly influences costs.

Fredrik Setterwall proposes to replace "renewable" with "sustainable" in the task definition, including "non-renewable" energy sources such as waste heat in the task's scope.

9.45 Introduction to IEA, Andreas Hauer

See presentation. The discussion during and after the presentation is noted here.

All participants are reminded that IEA cannot fund projects. Therefore, it is very important that all participants apply for European, national, or any other type of funding for the projects they intend to contribute to the task.

10.00 Introduction to SHC, Lex Bosselaar

There were no comments.

10.45 Brief introduction of the meeting participants

Each participant briefly presents their organisation and the work they would like to contribute to the task.

11.45 Introduction to the proposed task structure, Andreas Hauer

See presentation. The discussion during and after the presentation is noted here.

The discussion following the presentation focused on two basic considerations:

1. Why do we need a matrix structure? The main reasons for this are (1) to maximise the interaction between materials researchers and application experts, (2) to maximise knowledge exchange between groups working on adjacent topics, (3) to give the task an organisational structure that reflects the different emphasis, backgrounds, and working cultures of the two IAs.
2. Which applications do we include, and how do we subdivide them? Since many of the points discussed here were repeated in the afternoon discussion, they are noted there.

12.30 Lunch at ECN

13.30 Discussion on task structure

The group was separated into four groups, and each group was asked to discuss which types of applications and which types of activities should be included in the task. Each group's results was discussed in a plenary session, of which the main conclusions are noted below.

There was a relatively quick consensus on how to organise the material-related activities:

- Materials engineering, here defined as changing the properties of a material. This is a very important topic to include, reflected by the fact that a large amount of participants is interested in this activity.
- Materials processing. This is also very relevant, but only represented by a very small number of participants. This could be improved.
- Materials testing.
- Numerical modelling. It was noted that many participants are interested in doing this type of work, but only very few are actively doing it now.
- System integration, with the main objective to determine the need for different material properties. Many participants are already involved in this type of activity.

Other important points presented during this part of the discussion were:

- It is important to unite the different groups working on PCMs and TCMs instead of separating them in the organisation of the task.

There was much more discussion on how to organise the application-related activities. Arguments presented during the discussion were:

- "Energy source" (e.g. solar, industrial waste heat, etc.) could be used as a third axis in the matrix. However, this would seriously complicate the organisational structure.
- Criteria along which the application-related activities could be subdivided include function as well as physical parameters such as storage time, capacity, density, power, etc.
- Water storage could be used as a reference for some (particularly domestic) applications. However, for many of the other applications, particular industrial or mobile, it does not make sense to use water as a reference.

- Applications potentially relevant to the task include solar heating and cooling, heat pumps, adsorption cooling, industrial processes, industrial waste heat, district heating, concentrated solar power, food and medical, automotive, etc.
- In SHC Task 32 a well-defined reference system was used to compare different storage options. However, in this task we are dealing with very different technologies *and* very different applications, so such an intercomparison does not make sense. However, it does make sense to group the application-related activities along a selected number of typical applications.

Eventually, six topics were selected (indicated in brackets is the number of meeting participants that indicated activities relevant to this applications):

- seasonal solar thermal storage (8)
- building cooling (7)
- co- and tri-generation and heat pumps (6)
- district heating (2)
- industrial waste heat usage for building heating (5)
- concentrated solar power (2)

In addition, temperature control (e.g. for medical applications) was indicated as an interesting spin-off.

It was agreed to use this subdivision flexibly, i.e. keep the possibility open to add or combine topics during the task's progress.

16.30 Discussion on subtask division

The initial proposal was to organise the task in 4 subtasks: materials, applications, dissemination, and theoretical limits.

After some discussion, it was agreed to reduce this to two subtasks: one subtask on materials, reporting to the ECES ExCo, and one subtask on applications, reporting to the SHC ExCo.

According to the experience of the SHC ExCo, a separate subtask on dissemination is not always needed; the topic of theoretical limits will be included as a special type of "application".

Although the SHC IA focuses on solar, the SHC ExCo is not expected to object to the fact that a much broader range of applications is covered in this task. Nevertheless, this should be discussed at the upcoming SHC ExCo meeting.

18.00 End of Day 1

Day 2

9.00 Introduction, Wim van Helden

A summary of Day 1 was presented, as well as an updated version of the task structure, based on yesterday's discussion (see presentation).

9.30 Discussion on objectives, activities, and deliverables

Collectively, a table was created for each type of activitiy in the task, containing an overview of the objective, main activities, deliverables, and interested organisation for each activity. The table is available separately.

11.25 Announcement Symposium Bad Tölz, Andreas Hauer

See presentation.

11.30 Wrap-up by Wim van Helden

An inventory was made of the funding status of the meeting participants (see table below). In general, the funding status of this task is very good.

Country	Participant	Funding status	Remarks
SP	University of Zaragoza	+	Waiting for funding, almost sure, will know more in September.
DE	ZAE Bayern	++	Almost certainly funded.
DE	IWT Graz	+	Applied for funding, will know more in May, quite positive.
DE	Fraunhofer UMSICHT	–	Funding to be applied for.
CH	SPF	o	Applied for funding, 50/50 chance.
DE	ZAE Erlangen	–	Funding to be applied for.
SE	EcoStorage	++	Funded.
SP	Tekniker	++	Funded.
SP	Abengo Solar	o	Applied for funding.
DE	ITW Stuttgart	+	Applied for funding, positive.
NL	ECN	++	Funded.
NL	Entry	o	Unknown (not present during Day 2)
DE	Zeosys	–	Funding to be applied for.
UK	Ciba	++	Self-funded, depends on activities that will be contributed.
FI	VTT	–	Funding to be applied for.
DE	Vaillant	++	Self-funded, depends on activities that will be contributed.
SP	Inasmet	++	Funded.
CH	EMPA	++	Funded until Jan 2010.
FR	EDF	++	Self-funded.

It was decided that email was the most appropriate medium to continue the writing and editing of the task definition document. In addition, since 10 to 15 of this meeting's participants will be at the Eurosun conference in Lisbon in October, it is possible to hold an informal meeting there as well.

When asked how we could increase the participation of materials experts, it was suggested to

- use the Bad Tölz meeting to increase attention,
- contact the Polymer Competence Centre Leoben (PCCL) and the Dutch Polymer Institute (DPI),
- to present the task to the IEA ad-hoc group on science and technology,
- to use the Solar Keymark network meeting and Solar Thermal Industry Forum, organised by ITW Stuttgart on 10 and 11 June, respectively.

It was also decided that the OAs will create a brief presentation of the task (on a one-page leaflet and in some powerpoint slides), to be used by all.

The location of the upcoming kick-off meeting in January 2009 is to be determined. When interested in hosting this event, please contact the OAs.

Action list

- OAs: translate the meeting minutes into a draft Annex text, and send this around for comments.
- OAs: create a leaflet and some powerpoint slides, briefly presenting the task, to be used by all.
- OAs: have a first draft Annex text ready for the ExCo at the end of April.
- ALL: invite others to participate in the task.
- ALL: secure funding for their task work between June 2008 and January 2009.

Anhang 4:

Tagesordnung zum Kick-Off Meeting in Bad Tölz, 11.-13. März 2009

Programme of the
Kick-Off Meeting
of Task 42 / Annex 24
“Compact Thermal Energy Storage – Material Development and System Integration”

February 11-13, 2009
Bad Tölz, Germany

Draft Program

Wednesday, February 11th, 2009

14:00 – 15:00	Welcome and Introduction of Participants
	Roundtable Introduction
	Introduction to the IEA/ SHC /ECES (A. Hauer. /W.v. Helden)
15:00 – 16:00	Presentation of Projects within the Task/Annex

PCM I

State of the Art of Phase Change Material Development	H. Mehling	ZAE Bayern
Selection of materials with potential in thermal energy storage	Luisa F. Cabeza[1], Inés Fernández[2], Ingrid Martorell[1], Cecilia Castellón[1], Mónica Martínez[2]	1 GREA Innovació Concurrent, Edifici CREA, Universitat de Lleida; 2 Department of Materials Science & Metallurgical Engineering, Universitat de Barcelona
Improving the Thermal Conductivity in Phase Change Energy Storage Systems	Frank Bruno	Sustainable Energy Centre, Institute of Sustainable Systems and Technologies, University of South Australia.
Indoor "smart" plaster for thermal comfort and energy savings in buildings	Patricio Aguirre Mugica	INASMET
Synthesis and Characterization of Fatty Acid Inserted Comb-like PVA as Solid-Solid Phase Change Material for Thermal Energy Storage	Cemil ALKAN* , Ahmet SARI, Esra DOĞANGÜZEL	Department of Chemistry, Gaziosmanpaşa University, 60240 Tokat, Turkey

16:00 – 16:30	Coffee Break

16:30 – 18:30 Presentation of Projects within the Task/Annex (contd.)

TCM

Thermochemical Energy Storage Activities at the ZAE Bayern	E. Lävemann and A. Hauer	ZAE Bayern
Materials for thermochemical storage: characterization of salt hydrates	V.M. van Essen, M. Bakker and W.G.J. van Helden	Energy Research Centre of the Netherlands
HYBRID MOLECULAR DYNAMICS SIMULATIONS FOR MODELLING THERMOCHEMICAL HEAT STORAGE	S.V. Nedea, C.C.M. Rindt, A.A.van Steenhoven,	Technical University Eindhoven, Mechanical Engineering,
Liquid Desiccant Storage for High Solar Fraction Thermal Systems	Jane Davidson and Josh Quinnell	University of Minnesota
INTERSEASONAL SOLAR THERMAL ENERGY STORAGE FOR HOUSE HEATING THROUGH LiBr / H_2O ABSORPTION PROCESS: PRELIMINARY FEASABILITY STUDY	Lingai LUO[a], Nolwenn LE PIERRES , Hui LIEU	LOCIE-CNRS-Unversity of Savoie
HYDRATION AND DEHYDRATION OF SORPTION MATERIALS: EXPERIMENTS IN A SMALL-SCALE REACTOR	Camilo Rindt	Energy Technology Laboratory, Eindhoven University of Technology
Thermochemical storage using composite materials	Stéphanie HONGOIS, Philippe STEVENS	EDF R&D, Department ENERBAT
Planed work and contribution to the IEA SHC Task 42 & IEA ECES Annex 24	Paul Gantenbein et al.	Institut fuer Solarenergie SPF - HSR University of Applied Sciences of Rapperswil

19:30 “Bavarian Buffet”

Thursday, February 12th, 2009

09:00 – 10:30 Presentation of Projects within the Task/Annex (contd.)

PCM II

Preparation, thermal properties and thermal reliability of lauric acid/expanded perlite composite for thermal energy storage	Ahmet Sarı, Ali Karaipekli, Cemil Alkan	Department of Chemistry, Gaziosmanpaşa University, 60240, Tokat, Turkey
Recent PCM R&D Activities at Cukurova University	Halime Paksoy, Hunay Evliya, Ramazan Bilgin	Cukurova University, Chemistry Department, Adana, Turkey
Description of the current and future research activities on PCM	Elena Palomo	TREFLE – Université Bordeaux 1
HEAT TRANSFER IN PHASE CHANGE MATERIALS: ADVANCES IN MODELING AND EXPERIMENTATION	G. Ziskind	Ben-Gurion University of the Negev
Thermal Energy Storage for Comfort Cooling- Perspectives from Material Findings to System Integration	J. Chiu(a), V. Martin, F. Setterwall, B. Palm	(a) Department of Energy Technology, Royal Institute of Technology
Danish PCM Activities	Simon Furbo	Department of Civil Engineering, Technical University of Denmark
PCM Activities	Alexjandra Delgado Perez	University of the Basque Country
TES with PCM for cooling in buildings	Belén Zalba, José Mª Marín, Ana Lázaro, Pablo Dolado,	University of Zaragoza

10:30 – 11:00 Coffee Break

11:00 – 12:30 Discussion on the Workplan

12:30 – 14:00 Lunch

14:00 – 16:00 Discussion on the Workplan and on the Task/Annex activities and deliverables

16:00 – 16:30 Coffee Break

16:30 – 18:30 Discussion on the Task/Annex activities and deliverables and Annex structure

19:30 Dinner

.

Friday, February 13th, 2009

09:00 – 10:30	Bus Trip to Garching
10:30 – 12:00	Technical Tour I (PCM storages at ZAE Bayern, Garching)
12:00 – 12:30	Bus Trip to Munich
12:30 – 14:00	Lunch
14:00 – 15-00	Technical Tour II (Zeolite and LiCl Storages, ZAE Bayern)
15:00	End of Meeting

The meeting ends in Munich, where you have excellent connections to the airport and the central station.

Presentation of Activities

We will have more than 60 participants and about 22 presentations. Therefore you will be given approximately 5-10 minutes to present your work. There should be time for discussion after your presentation. So please do not have more than 5 - 10 slides in your presentation!

Anhang 5:

Tagesordnung zum 2. Task-Experts-Meeting in Lleida, 22.-24. September 2009

Draft Programme of the
Second Expert Meeting
of Task 42 / Annex 24
“Compact Thermal Energy Storage – Material Development for System Integration”

23 – 25 September
Lleida, Spain

Program

Wednesday, 23 September, 2009

10:00 – 13:00 Meeting of Working Group Leaders (Chair: Andreas Hauer, Wim van Helden)

Determination of Agenda (chair)

General announcements (all; IEA, national programs, international projects, …)

Progress reports (all WG leaders)

- work in progress
- results achieved
- progress on Task deliverables
- new participants
- presentations and publications
- …

Discussion on Agenda of the Expert Meeting (chair)

Work Plan (chair)

Participation Letters (chair)

Upcoming events: conferences, workshops, projects, calls, … (all)

Setting dates and places for next expert meetings

Items for parallel sessions (all)

Action List (chair)

13:00 – 14:00 Lunch

14:00 – 15:00 Plenary session (chair)

Welcome and agenda (chair)

Notes of previous meeting and Action List (chair)

Introduction of new participants (chair)

5 minute presentation of new participants

- University of Ottawa, Handan Tezel
- Aidico, Maria Dolores Romero
- ASiC, Bernhard Zettl

- …

General announcements (all)

Short progress updates

- general
- working groups

WGA1 Material Engineering and Processing (Elena Palomo, Viktoria Martin)

WGA2 Test and Characterisation (Stefan Gschwander)

WGA3 Numerical Modelling (Camilo Rindt)

WGA4 Apparatus and Components (Wim van Helden)

WGB1 Cooling (Halime Paksoy)

WGB2 Heating and DHW (Jane Davidson)

WGB3 High Temperature (Lluisa Cabeza)

WGC1 Theoretical Limits (Eberhard Laevemann)

WGC2 System Integration (Wolfgang Streicher)

Parallel sessions: who and where (chair)

15:00 – 16:00 Parallel Sessions Subtask A: Materials

Draft Agenda:

Opening and welcome

Agenda

Notes of previous meeting, action list

General progress in Working Group (WG leader)

Highlights from projects

Invited short presentation (determined beforehand by WG leader)

Progress of WG activities, milestones, results

Timetable

Action list

16:00 – 16:30 Coffee Break

16:30 – 18:30 Parallel Session Subtask A (continued)

21:00 Dinner

Thursday, 24 September, 2009

09:00 – 10:30 Parallel Sessions Subtask B: Applications

(See Agenda above)

10:30 – 11:00 Coffee Break

11:00 – 12:30 Parallel Sessions Subtask B (continued)

12:30 – 14:00 Lunch

14:00 – 16:00 Parallel Sessions Cross Cutting Issues

(See Agenda above)

16:00 – 16:30 Coffee Break

16:30 – 18:30 Plenary Session

- Agenda
- Summaries from the Working Groups
- Task results, milestones, timetable
- Modifications to Work Plan
- Presentations and Publications
- Upcoming events
- International programs and collaborations
    - COST action
    - ITN, Initial Training Network
    - Technology Roadmap of the RHC-ETP
    - ….
- Dates and places for next expert meetings
- Action list
- Excursion tomorrow: what, where and when

21:00 Dinner

.

Friday, 25 September, 2009

Excursion

Anhang 6:

Tagesordnung zum 3. Task-Experts-Meeting in Bordeaux, 7.-8. Juni 2010

PRELIMINARY PROGRAM

Tuesday, 6 July

14:00 – 18:00	Working Group Leaders meeting.

Wednesday, 7 July

9:00 – 10:30	Plenary session
10:30 – 11:00	Coffee break
11:00 – 13:00	Plenary session
13:00 – 14:00	Lunch
14:00 – 16:00	Parallel Working Group sessions
16:00 – 16:30	Coffee break
16:30 – 18:00	Parallel Working Group sessions
21:00	Dinner – “Le café maritime”

Thursday, 8 July

9:00 – 10:30	Parallel Working Group sessions
10:30 – 11:00	Coffee break
11:00 – 13:00	Parallel Working Group sessions
13:00 – 14:00	Lunch
14:00 – 16:00	Plenary meeting
16:00 – 16:30	Coffee break
16:30 – 18:00	Plenary meeting

Anhang 7:

Third Semi Annual Status Report

IEA SHC/ECES Task/Annex 4224

TU Graz
Graz University of Technology

AEE INTEC

arsenal research
Ein Unternehmen der Austrian Research Center

Task 42 Annex 24

Compact Thermal Energy Storage: Material Development for System Integration

Third Semi-annual Status Report

November 2009 – June 2010

Submitted for
the 69th ECES ExCo meeting, 19-21 May 2010, Turku, Finland,
and the 67th SHC ExCo meeting, 22-24 June 2010, San Francisco, USA.

Operating Agent SHC:
Wim van Helden
Energy research Centre of the Netherlands ECN
The Netherlands

Operating Agent ECES:
Andreas Hauer
ZAE Bayern
Germany

Contents

1 Short Description of Task 42

From past IEA SHC and ECES tasks it was concluded that a broad and basic research and development initiative is needed to find and improve compact thermal energy storage materials. The IEA joint Task/Annex 42/24 brings together experts from both the materials development field and the systems integration fields. In four years, the task aims at having finished the first steps towards a new generation of thermal storage technologies.

1.1 Objectives and Scope

Objective

The overall objective of this task is to develop advanced materials and systems for the compact storage of thermal energy. This can be subdivided into seven specific objectives:

- to identify, design and develop new materials and composites for compact thermal energy storage,
- to develop measuring and testing procedures to characterise new storage materials reliably and reproducibly,
- to improve the performance, stability, and cost-effectiveness of new storage materials,
- to develop multi-scale numerical models, describing and predicting the performance of new materials in thermal storage systems,
- to develop and demonstrate novel compact thermal energy storage systems employing the advanced materials,
- to assess the impact of new materials on the performance of thermal energy storage in the different applications considered, and
- to disseminate the knowledge and experience acquired in this task.

A secondary objective of this task is to create an active and effective research network in which researchers and industry working in the field of thermal energy storage can collaborate.

Scope

This task deals with advanced materials for latent and chemical thermal energy storage, and excludes materials related to sensible heat storage. The task deals with these materials on three different scales:

- material scale, focused on the behaviour of materials from the molecular to the ‘few particles’ scale, including e.g. material synthesis, micro-scale mass transport, and sorption reactions;
- bulk scale, focused on bulk behaviour of materials and the performance of the storage in itself, including e.g. heat, mass, and vapour transport, wall-wall and wall-material interactions, and reactor design;

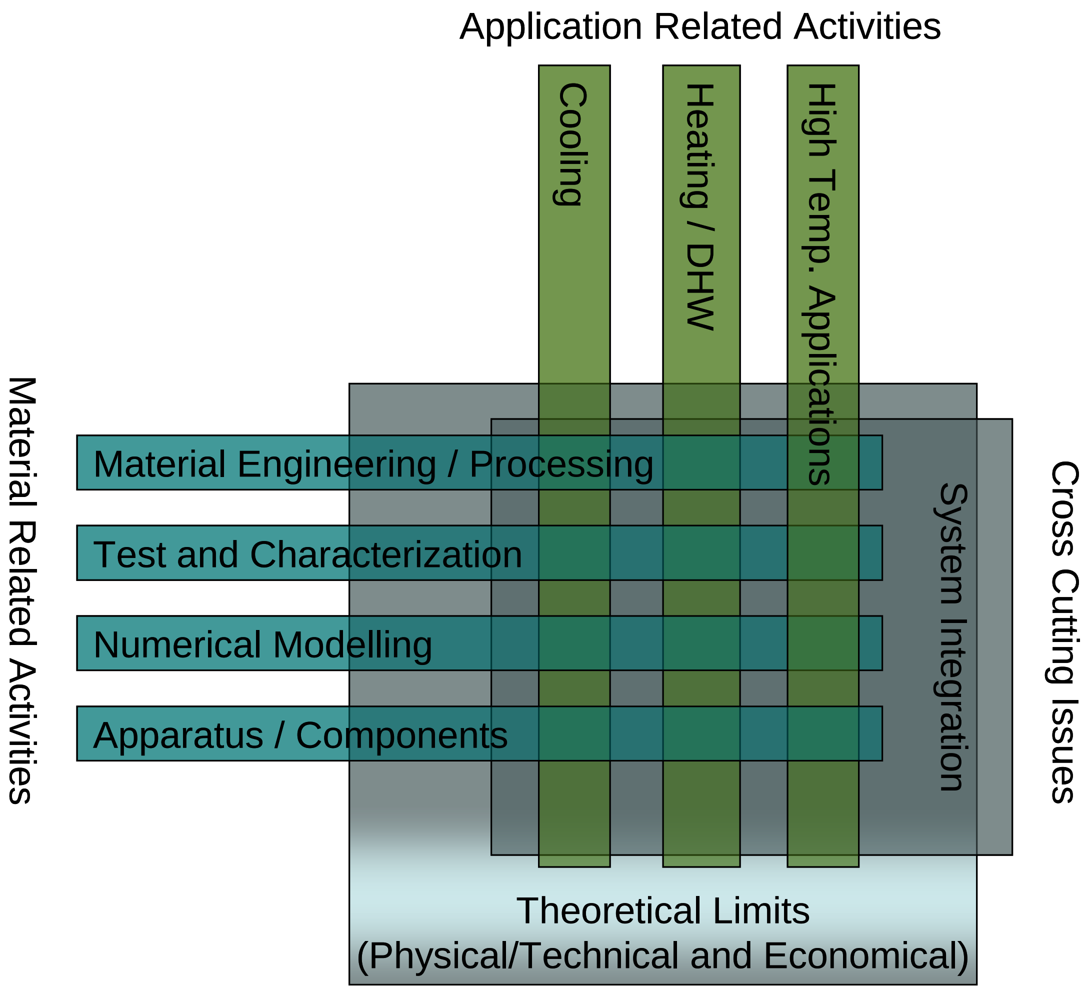
- system scale, focused on the performance of a storage within a heating or cooling system, including e.g. economical feasibility studies, case studies, and system tests.

Because seasonal storage of solar heat for solar assisted heating of buildings is the main focus of the SHC IA, this will be one of the primary topics of this task. However, because there are many more relevant applications for TES, and because materials research is not and can not be limited to one application only, this task will focus on multiple application areas.

In the Task kick-off meeting it was decided to subdivide the Applications Subtask into three Working Groups, corresponding to three different temperature levels of thermal energy storage, as depicted below.

Structure

To achieve the maximum amount of cross-fertilisation between the different backgrounds of the two Implementing Agreements and experts in this Joint Task, the Task is organised in a matrix-like structure (see diagram below).



The working Group Leaders for all the working groups are listed in the table below. The Working Group Leader will guard the co-operation within the group, optimise the communication and stimulate the contribution of the participating experts to the working group deliverables.

	Materials:	**WG Leader**
WGA1	Material Engineering and Processing	Elena Palomo (Univ.Bordeaux, FR) and Viktoria Martin (KTH, SE)
WGA2	Test and Characterization	Stefan Gschwander (ISE, DE)
WGA3	Numerical Modelling	Camilo Rindt (TUE, NL)
WGA4	Apparatus and Components	Wim van Helden (a.i.) (ECN, NL)
	Applications:	
WGB1	Cooling (0 °C – 20 °C)	Halime Paksoy (Cukurova Univ, TR)
WGB2	Heating / DHW (20 °C – 100°C)	Jane Davidson (Univ.Minnesota, US)
WGB3	High Temp. Appl. (> 100 °C)	Luisa Cabeza (Univ.Lleida, ES)
	Cross Cutting:	
WGC1	Theoretical Limits	Eberhard Lävemann (ZAE, DE)
WGC2	System Integration	Wolfgang Streicher (TUGraz, AT)

2 Progress Report

The official start of the Task is 1 January, 2009. This third progress report covers the activities from November 2009 until June 2010.
Below is the table giving an overview of the Task4224 expert meetings. Two meetings were held and a third was planned in April 2010. For the fourth and the fifth meeting the cities and countries have already been determined.

	Place	Country	Date	# part.
1	Bad Tölz	Germany	11-13 February, 2009	69
2	Lleida	Spain	21-23 September, 2009	71
3	Bordeaux	France	21-23 April, 2010* 7+8 July, 2010	
4	Graz	Austria	26-28 September, 2010	
5	Ulster	United Kingdom	March, 2011	
6	t.b.d.	United States	Fall 2011	

The third expert meeting was planned in Bordeaux at the end of April. Due to the very limited air travel possibilities in Europe, caused by the Icelandic volcano eruption, the hosting organisation and the operating agents decided to cancel this meeting.
As a result, this report does not contain the outcomes and discussions of the meeting. Shortly after the cancelled meeting a new date for the third meeting was agreed upon. This will be 7 and 8 July 2010, now really in Bordeaux.
As the working groups did not convene, the progress report is now subdivided into descriptions of the work in progress in the participating organisations.
In the following, 15 organisations shortly describe the scientific progress they achieved in the past period. Additionally, 5 project short descriptions are given.

2.1 Technical University of Denmark, DTU

Scientific progress

A number of investigations have been carried out with the aim to elucidate how best to design a seasonal heat storage based on the salt hydrate sodium acetate trihydrate. The heat storage will be suitable for solar heating systems, which can fully cover the heat demand of low energy buildings under Danish conditions.
The heat storage concept is based on the advantage of stable supercooling of the salt hydrate to achieve a partly heat loss free heat storage.
The following questions have been answered by means of separate investigations.

- Which heat storage temperature level is needed during charge periods in order to achieve a stable supercooling of the heat storage material?
- What is the optimum size of each module consisting of one separate container of the heat storage?
- How is the supercooled salt solution activated in the most reliable way?
- How are large quantities of the heat storage material best filled into the modules of a heat storage?

The questions were answered by a number of small scale laboratory experiments. The heat storage material in all the experiments is a mixture of 58% (weight%) NaCH3COO and 42% (weight%) water. Experience has shown that this mixture, which has a melting point of 58°C, supercools in a stable way. Based on the answers a laboratory module of a seasonal heat storage was built, see figure 1. The mass of the salt water mixture in the module is 305 kg, corresponding to a salt water mixture volume of about 234 liter.

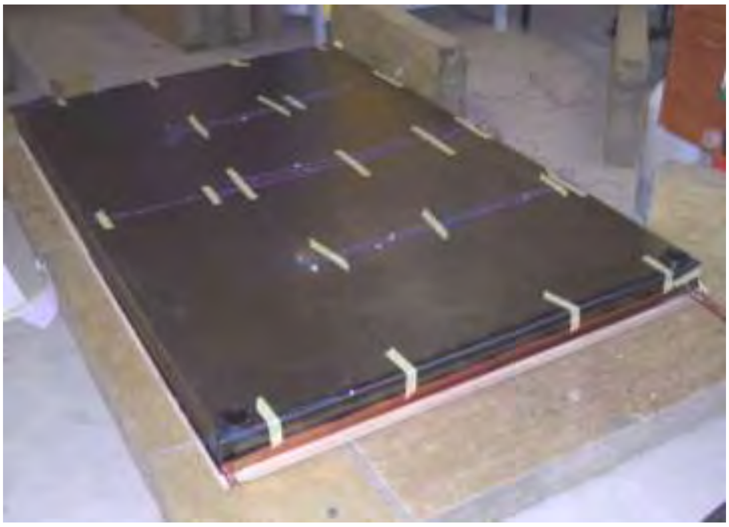


Figure 1. Photo of 200 litre module tested in the laboratory.

The seasonal heat storage module will be tested in a laboratory test facility during the summer 2010.

2.2 AIDICO, Spain

Scientific progress

AIDICO is carrying out some research about the microencapsulation of hydrated salts. Hydrated salts with different melting points have been selected. The calcium chloride salt has been selected to carry out the experimental work and microencapsulation trials in this report.

Phase segregation is one of the problems that some salt hydrates exhibit when used as PCM. This means that under continuously melting and solidifying, the difference in density between the water and the salt components of the salt hydrate results in segregation. The consequence is a bad crystallization of the compound, and a change in the thermo physical properties of the PCM.

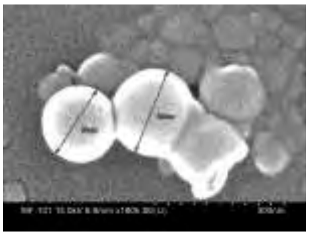
Segregation can be prevented by changing the properties of the salt hydrate with the addition of another material that can hinder the heavier phase to sink to the bottom. This can be achieved either with gelling or with thickeners. Gelling means the addition of a cross linked material to the salt. Thickening means the addition of a material to the salt hydrate that increases the viscosity and hereby holds the salt hydrate together. This is beneficial not only for preventing gross segregation of the lower hydrates or anhydrous salts formed in peritectic reactions, but is also helpful in suspending insoluble nucleating agents.

The other problem is super cooling of salt hydrates when they freeze because of their weak nucleation. Anhydrous salts and aqueous solution of salts are formed when the inorganic salt hydrates melt. On freezing, rehydration may start only at the solution-precipitate interface. Thus, rehydration cannot further proceed because the salt forms a contact barrier between the liquid and the anhydrous salt solution. The consequence is a bad crystallization of the compound and a change in the thermo physical properties of the PCM.

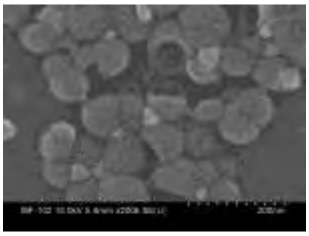
Therefore, we are working with different nucleating agents to analyze its effect on the super cooling of hydrated salts.

Some micrographs corresponding to the microencapsulation of hydrated salt with two different nucleating agents are shown below. Although microcapsules have been successfully obtained (as observed by infrared spectroscopy, SEM, particle size distribution), research will continue on the way to find optimum crystallization of the hydrated salts to improve thermal stability to the salts.

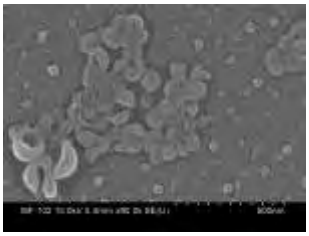
Microencap-$CaCl_2 \cdot 6H_2O$



Microencap-$CaCl_2 \cdot 6H_2O$ with $SrCl_2 \cdot 6H_2O$



Microencap-$CaCl_2 \cdot 6H_2O$ with $Ba(OH)_2 \cdot 8H_2O$



These results are included in the reports of the European project: Multi--source energy storage system integrated in buildings (MESSIB).

We have no presentations regarding the microencapsulation of hydrated salts. Some publications have been presented in international congresses regarding the use of PCMs in construction materials. See the presentation list below.

2.3 University of Zaragoza,Spain

Scientific progress

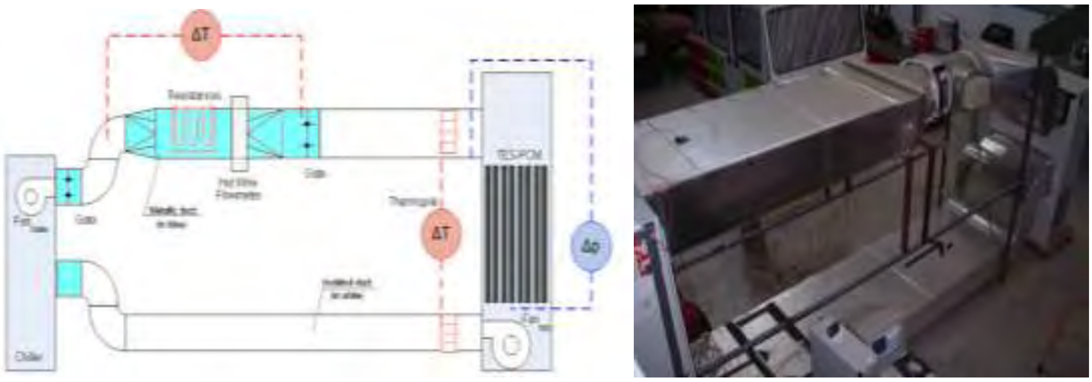


Figure: Experimental PCM-air heat exchanger setup diagram and photo

Results achieved

- Thermal properties: rheological measurements and analysis already under way: h(T) and thermal conductivity measurements of new materials and PCM slurries continued.
- Test characterization with PCM sample initiated (DSC measurements already carried out for the 98% Octadecane sample), for Working Group A2.
- Experimental setup starting to test PCM slurries as HTF.

- PCM-air heat exchanger prototype results sent to scientific journals, 2 papers:
    - Experimental results and analysis
    - Numerical model and validation

2.4 LOCIE Laboratory - Université de Savoie, France

Scientific progress

Results achieved

The LOCIE laboratory focuses on long term heat storage through thermochemical technology. The principle of the storage is presented in ref [2] to [5] cited below. A multi-criteria evaluation had been performed to determine the most interesting absorption couple for the process: $LiBr/H_2O$. The last semester has been dedicated to the design of the future prototype of solar heat storage by $LiBr/H_2O$ absorption, and to the determination of the potential performances of the system through numerical simulation. As an example of the simulation results, the dimensions of the storage tanks for a efficient family house that would need 1800 kWh of heat during the year is given in figure 2, as a function of the heat delivery temperature.

We can see in this figure the major interest of increasing the heat capacity of the storage by the management of the crystallisation in the storage tank: the size of the tank is decreased by a factor of about 2 when crystal appearance is allowed. We can also see the classical effect of the heat production temperature: the higher the temperature, the higher the sensible heat losses and thus the lower the heat capacity of the storage.

Problems encountered

The major problem of this technology using water as the working fluid is the low pressure in the process. The problems encountered are thus linked to the vacuum process: pumps functioning at low pressure, leakages in the prototype… But these technological problems are being solved progressively.

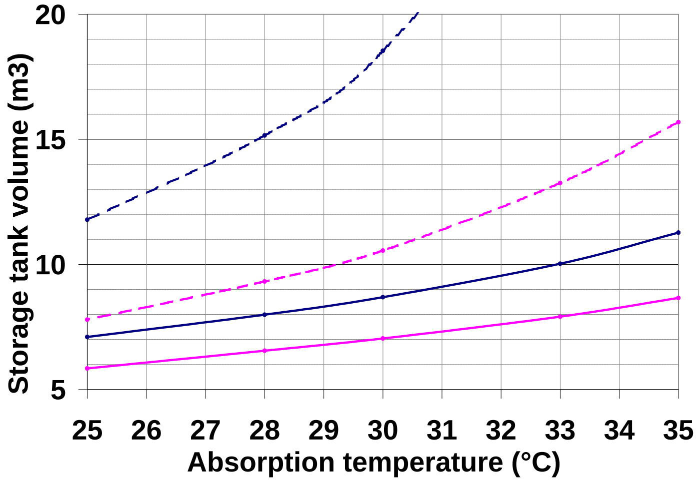


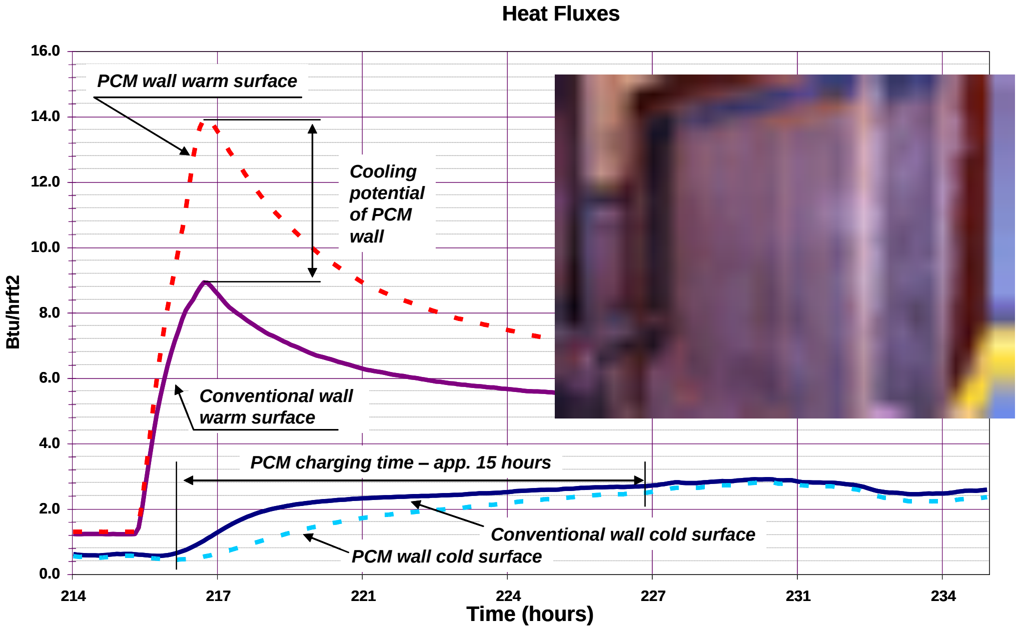
Figure 2: dimensions of the storage tank as a function of the heat delivery temperature; rose lines: evaporator temperature of 5°C, blue lines: evaporator temperature of 10°C; dotted lines: without crystals in the tank, continuous lines: with crystal in the tank.

2.5 Oak Ridge National Laboratory, USA

Scientific progress

dynamic Hot Box testing of wood frame wall Containing PCM-Enhanced cellulose insulation

A new PCM-enhanced thermal insulation was developed to generate a thermal mass effects in building envelope. Small amounts of different cellulose–PCM blends were produced with the use of a pilot-scale production line. In this project, microencapsulated non-paraffinic PCM was used. The amount of PCM in the cellulose was monitored with the use of a scanning electron microscope. It was observed that in PCM amounts higher than 10%, the PCM formed clusters of pellets between cellulose fibers. The fiber structure of the cellulose insulation was able to support the addition of up to 40% by weight of PCM microcapsules without segregation.



Heat flux measured during the dynamic hot-box experiment performed on the 2x6 wood stud wall containing PCM-enhanced cellulose insulation.

A nominal 8×8 ft (2.4×2.4 m) wood-frame wall specimen was used for dynamic hot-box testing of a PCM–cellulose blend. The test wall was constructed with 2×6 in. (6×15.2 cm) wood framing installed 16-in. o.c. (40 cm). Three wall cavities were insulated with plain cellulose of a density about 2.6 lb/ft3 (42 kg/m3). Three remaining wall cavities were insulated with a cellulose–PCM blend of a density of about 2.6 lb/ft3 (42 kg/m3) and containing about 22% by weight of PCM.

At the beginning of the hot-box measurement, temperatures on both surfaces of the specimen were stabilized at about 65°F (18.3°C) on the cold side and 72°F (22.2°C) on the warm side. Next, the temperature of the warm side was rapidly increased to 110°F (43.3°C). Next, after about 120 h, the hot-box heaters were turned down and the temperature of the warm side of the wall was reduced by natural cooling to 65°F

(18.3°C). The figure above depicts test-generated heat fluxes for both parts of the wall, recorded during the rapid warm-up excitation.

It took 15 h to charge the PCM material within the wall. Heat fluxes on both sides of the wall were measured and compared. For three 5-hour time intervals, heat fluxes were integrated for each surface. Comparisons of measured heat flow rates on the wall surface, which was opposite the thermal excitation, enabled an estimate of the potential thermal load reduction generated by the PCM. In reality, most daily thermal excitations generated by solar irradiance are no longer than 5 h (peak-hour time). Heat flux was measured during the first 5 h after the thermal ramp. The PCM-enhanced cellulose material reduced the total heat flow through the wall by over 40%. The same PCM technology was utilized in test house built in 2010 in Oak Ridge, TN – see the figure below. In this house two-layer, double frame walls were used in order to maximize thermal resistiace. First field test results will be presented during the next IEA Task/Annex 42/24 meeting in Graz, Austria.

ORNL test house during construction and installation of the PCM-enhanced cellulose insulation in the double frame wall.

2.6 National Institute of Chemistry Ljubljana, Slovenia

Scientific progress

Results achieved

Microporous aluminophosphate, microporous zeolite P, disordered mesoporous metal silicate and composite with CaCl2 were prepared. Materials were structurally characterized by XRD, TG, SEM/TEM and nitrogen physisorption.

Microporous aluminophosphate was sent to Fraunhofer-Institute for Solar Energy Systems to determine the thermo chemical properties.

Zeolite P was sent to Bavarian Center for Applied Energy Research to the group for Heat Storage Systems for the determination of thermo chemical properties.

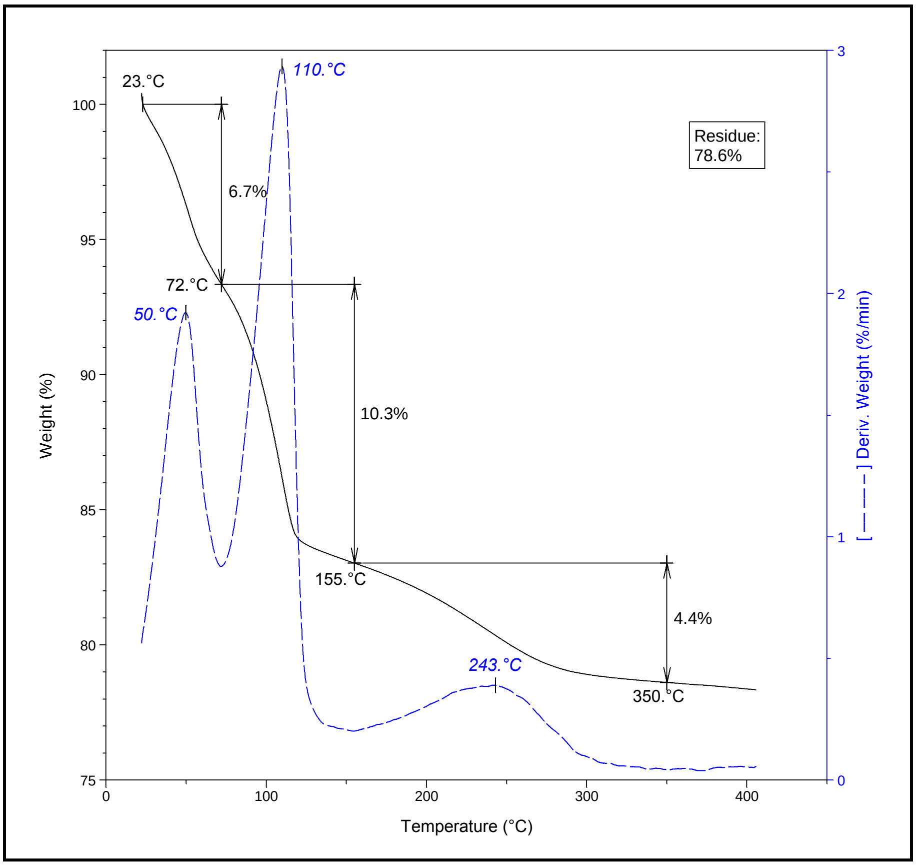


Figure 3 shows TG/DTG curves of Zeolite P.

We have developed a new disordered mesoporous metal silicate with textural porosity for which the pore diameters range from 3 nm to 25 nm. Composite material with CaCl2 was prepared by wet impregnation. X-ray powder analysis of both materials shows similar XRD patterns for both samples with no additional maxima due to CaCl2. A difference between these two samples can be noticed in water loss by thermogravimetrical analysis. Both materials were placed under NH4Cl solution for 3 days. Composite material shows higher water loss in comparison to pure mesostructured metal silicate in Figure 4.

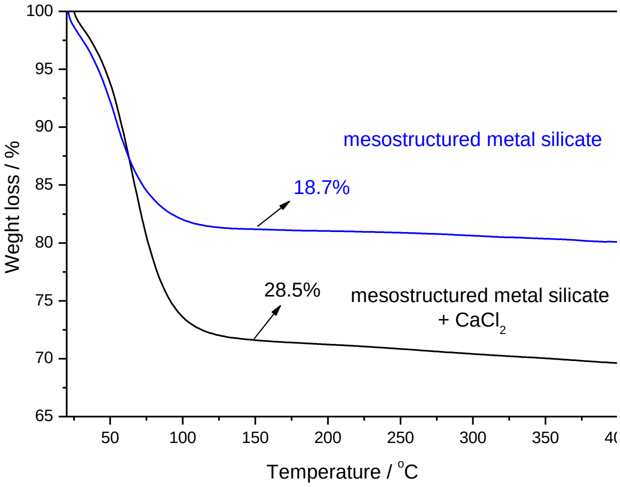
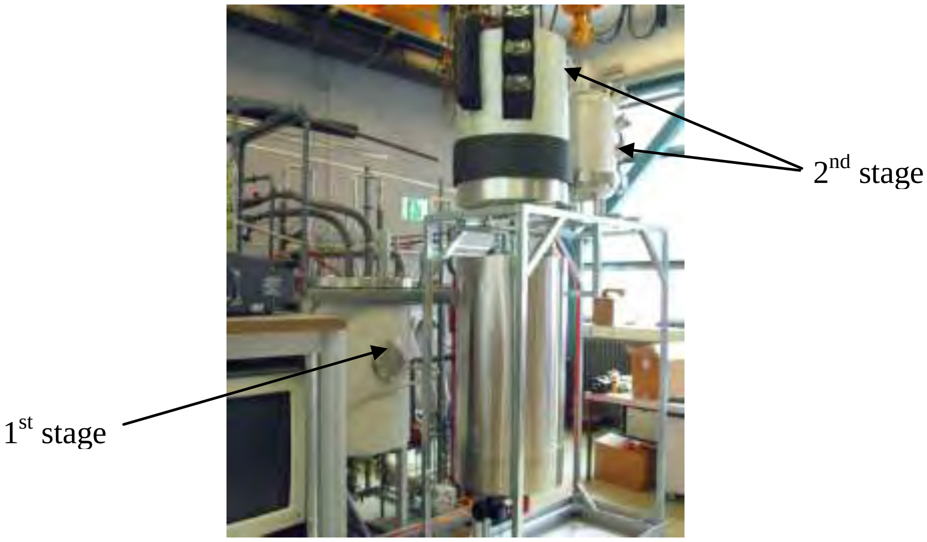


Figure 4: TG curves of mesostructured metal silicate and its composite with CaCl2.

2.7 EMPA Dübendorf, Switzerland

Scientific progress

We have installed the second stage of the heat/mass exchanger systems. This second stage has a complete new design to overcome the crystallisation issue of the first stage. Currently, there are measurements done to calculate parameters and system specific values (UA, heat losses etc.). These parameters shall be used in a TRNSYS simulation. The changes and improvement of the prototype now lead to a complete new TRNSYS type which is written in parallel to the other work done on the prototype.



Problems encountered:

-To find leaks, where the losses of vacuum occurs, is time consuming.
-The new TRNSYS 17 has some bugs in the programming environment.

2.8 Leuphana University of Lueneburg, Germany

Scientific progress

Results achieved

The group got started with method development for TGA/DSC to test different storage materials for high and low temperature thermochemical storage. At the moment, testing of different materials with regard to storage capacity, charging/discharging power in relation to water vapour partial pressure and layer thickness is conducted. An Aim is set at the testing of mixtures.

With regard to thermochemical storage, a market study for different applications was conducted (confidential).

2.9 ECN – Energy research Centre of the Netherlands

Scientific progress

Results achieved and problems encountered

A literature inventory supported by experiments identifies magnesium chloride hexahydrate ($MgCl2.6H2O$) as most promising material for compact seasonal heat storage in the built environment. Although the material is able to store and release heat under practical conditions, it was found that during the heat release (hydration) the material agglomerates and expands. This is an undesired effect since it results in the formation of a hard impermeable layer that destroys the open structure of the material and severely limits the ability to dehydrate again. As a solution, several carrier materials were investigated to stabilize the salt hydrate during hydration. Two promising carrier materials were found that were capable to contain large amount of salt (70 wt% and 80 wt%). Additionally, no volume expansion was observed due to the flexibility of the carrier material and the open structure was preserved after several cycles. However, both carrier materials were found to degrade when exposed to high temperature (130°C) during hydration. Current research focuses on finding new carrier materials.

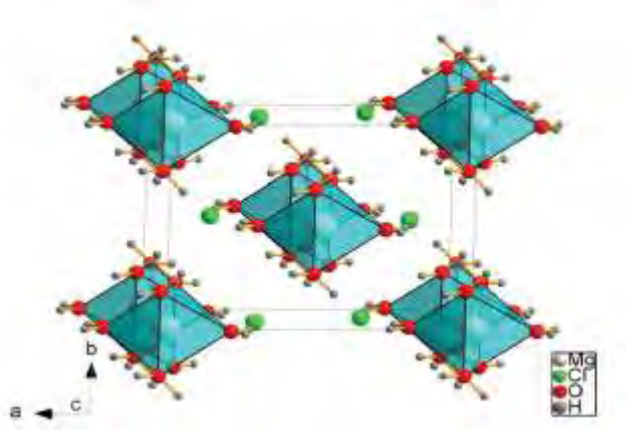
A first technical and economical evaluation of four thermochemical heat storage systems (open/close, integrated reactor and storage or separate reactor and storage) indicated that the atmospheric pressure fixed bed reactor is most cost effective. Based on this evaluation and first experiments, it was decided to build a atmospheric pressure fixed bed reactor capable of storing 300 gram material. The material inside the reactor was hydrated using moist air (20°C and 12 mbar water vapor pressure) and dehydrated using hot dry air (130°C). First results show that, despite heat losses and gas leakages, the air can be heated to 53°C, which is close to the temperature required for hot tap water (60-65°C). Current research focused optimization of the reactor. Also, first test with a larger reactor capable of storing 1 kg material are planned.

2.10 Energy Technology group, Eindhoven University of Technology, The Netherlands

Scientific progress

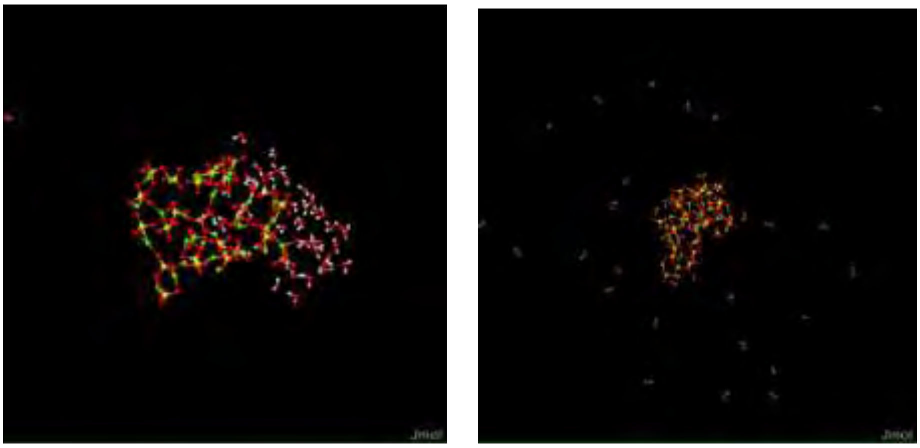
Results achieved

1. A study on the molecular structure of two salt hydrates (hydrated magnesium sulphate and magnesium chloride) as candidate materials for thermochemical heat storage.



The crystal packing of $MgCl_2\_6H_2O$ (Sugimoto et.al. 2007) in a parallel projection approximately down the crystallographic c-axis.

2. Preliminary knowledge on statistical mechanics and molecular dynamics simulations. Introduction to the formulation of molecular dynamics simulation from Newton's laws of motion by using inter particle potential and a method on how to use molecular dynamics results to calculate macroscopic quantities.
3. Model for hydration/dehydration reactions in salt hydrates. In order to model reactions a reactive force field (Reaxx) is to be used. Introduction and preliminary results for reactive force field and basic formulations of a quantum simulation method Density Functional Theory.



Molecular structures obtained using the studied reactive force fields. Left: initial configuration. Right: end configuration.

4. Development of a new reactor for the performance of hydration and dehydration experiments of thermochemical heat storage materials. In comparison to the former reactor the new reactor is equipped with many more temperature sensors. This enables detailed energy balance calculations of the reactor system and opens the possibility for validation of numerical the results of macro-scale heat and mass transfer calculations. A main difference with the former reactor is the flow direction which is such that the reactor runs now in fixed-bed mode.

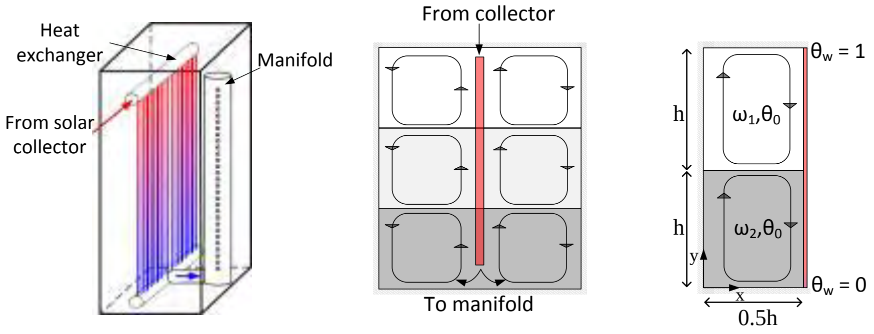
Problems encountered:

1. Force fields for the hydration/dehydration of magnesium sulphate need QM validation.
2. There is a high need for validation of the MD results. for example the calculated crystal structure needs experimental validation, the calculated pressure, temperature and density need validation with another molecular dynamics tool and the water model should be compared with other existing models.
3. Accurate measurements of the vapour content of the outflow in the experiments need special attention.

2.11 University of Minnesota, USA

Scientific Progress

We have completed computational fluid dynamic simulations to investigate sensible and absorption solar thermal energy storage in a single vessel. The goal of this work was to demonstrate that an immersed vertical tube heat exchanger allows a tank to be charged and discharged with sensible energy while preventing regions of different sorbent (calcium chloride) concentration from mixing. In this report the tank design and numerical model are outlined and some encouraging results are presented. Combining sensible energy storage and absorption storage in a single vessel is an improvement over water-based storage, but introduces new engineering challenges. For closed cycle systems, the combination of both storage mechanisms in a single vessel provides a material energy storage density 2.35 times that of sensible storage from water. The sensible energy storage enables a conventional solar thermal combi-system, while the absorption medium (aqueous calcium chloride liquid desiccant) is used in liquid desiccant based HVAC processes, such as heat pumping, dehumidification, or absorption cooling. High performance sensible energy storage is enabled with thermal stratification. The absorption storage is preserved by preventing the mixing of different $CaCl_2$ mass fraction. The challenge is to develop a storage tank that enables the benefits of both of these energy storage mechanisms, principally by managing buoyancy that is a function of salt fraction and temperature.



(a) (b) (c)

Fig 5. a) Concept to manage temperature and mass fraction in a liquid desiccant storage tank during charge and discharge (shown in the charge configuration); (b) cross-sectional view (without manifold) indicating convection cells as the tank is heated; (c) computational domain for numerical simulations.

Design

A storage tank design is introduced that uses an immersed heat exchanger and stratification manifold to thermally stratify the tank and to minimize mixing between regions of different $CaCl_2$ mass fraction. This approach separates energy addition from fluid addition/extraction. For instance, during charging, as shown in Fig. 5(a), incoming $CaCl_2$ solution from the solar loop is passed to the top of an immersed vertical heat exchanger. As the solution descends through the heat exchanger, the tank is heated top-to-bottom via natural convection within each layer of similar mass fraction. Cooled fluid exits the heat exchanger at the bottom of the tank where it enters a vertical stratification manifold. The $CaCl_2$ solution rises through the manifold and enters the tank at the vertical location where it is neutrally buoyant. On the tank-side of the heat exchanger, the density gradient between regions of different $CaCl_2$ mass fraction will result in the formation of layered convection cells as shown in Fig. 5(b). It is anticipated that the indirect heating will thermally stratify the tank while the strong density gradient at the interface between regions of similar mass fraction will suppress convection motion at the interface and as a result mixing by mass fraction.

Numerical Study

The objective of the numerical model is to observe transient heating and mass transfer during charging from an immersed vertical heat exchanger over a range of practical values of Rayleigh number and buoyancy ratio. The two-dimensional computational domain is shown in Fig 5(c). Half of the tank is modeled due to symmetry. The tank volume is initially split between H_2O and a strong $CaCl_2$ solution by a sharp density interface. A linear temperature profile is imposed on the right wall at t = 0 to simulate heating from the immersed heat exchanger. All other walls are adiabatic. The Rayleigh number, Ra, is varied between 3×10^5 and 3×10^8 and the initial buoyancy ratio, N, is varied from 13 to 131. Initially, the tank is quiescent and isothermal. Boundary conditions for velocity are no-slip and impermeable at all solid surfaces.

Results

Contour plots of dimensionless velocity magnitude, temperature, and $CaCl_2$ mass fraction are given at different times throughout the charging for $Ra=3\times10^8$ and N=131 in Fig 6. Upon heating, boundary layers develop within each region of homogenous $CaCl_2$ concentration on the heat exchanger wall. During charging, convection cells develop on either side of the density interface and the tank becomes thermally stratified. After the boundary layer development, the velocity near the density interface is <1% of the boundary layer velocity because momentum from the boundary layer is dissipated by viscosity. Thus, the mass transfer across the interface by convection is small. After the tank is heated, the total mass transfer is negligible and mainly due to the thickening of the interface by diffusion. Similar trends were found for all lower values of Rayleigh number and buoyancy ratios studied. This suggests that the layered configuration results in temperature stratification and low mixing under a wide variety of temperature and salt concentrations. These promising results are now being used to design an experimental prototype.

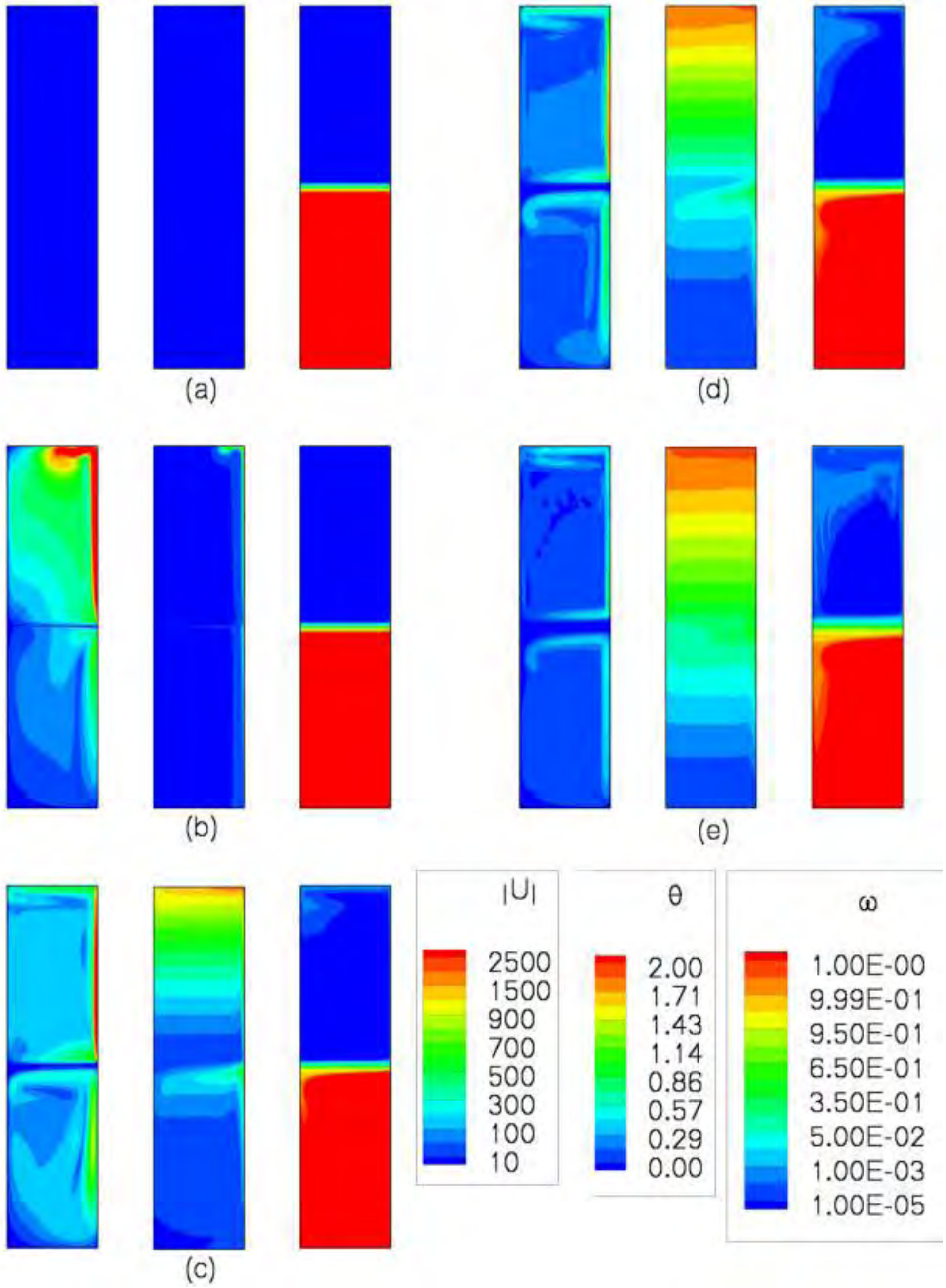


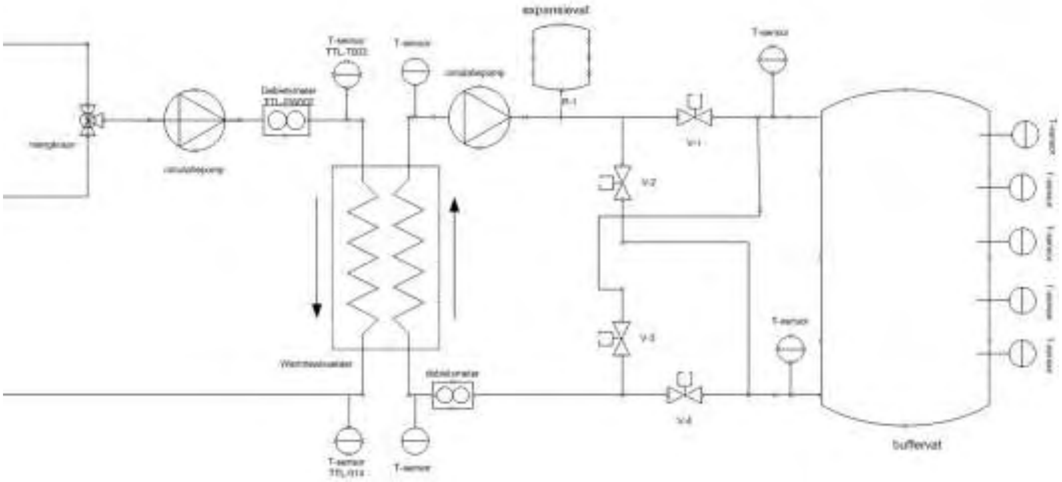
Figure 6. Dimensionless velocity magnitude, temperature, and mass fraction contours for Ra = 3×10^8, N = 131, Pr = 3.3, Le = 158 at (a) $\tau = 0$; (b) $\tau = 9.8\times10^{-4}$; (c) $\tau = 3.1\times10^{-3}$; (d) $\tau = 7.4\times10^{-3}$; (e) $\tau = 1.5\times10^{-2}$

2.12 VITO (the Flemish Institute for Technological Research), Belgium

Scientific progress

The aim of the project is to develop a short term compact thermal energy storage system for a heat pump or a micro combined heat and power system in a dwelling. The storage system is used in order to make a heat pump or a micro chp more flexible in a smart grid.

In 2009 a test bench for water storage systems with pcm materials (melting point between 30°C and 90°C) was constructed. The test bench was coupled with the dynamic test infrastructure of the thermo-technical laboratory. First test were performed on aluminum bottles of one liter filled with pcm and integrated in the storage vessel. The used paraffin was RT 58. A specific loading / unloading test cycle was set up in order to characterize the impact of the pcm in a storage vessel. The test results showed an impact of the pcm in the storage capacity especially at low temperature difference between melting temperature and loading / unloading temperatures. There can be an advantage by introducing pcm material in a storage tank but 1 liter bottles are not the right casing for the pcm due to the low thermal conductivity of the material.
We started to work at three alternatives for using pcm material for a compact thermal energy storage.



Scheme of the test installation

Picture of the test installation

2.13 CIEMAT, Spain

Scientific progress:

ACTIVITY 1: *Supplying information about the requirements and outputs of solar thermal power plants for advanced heat storage systems.* During this period, CIEMAT has been involved in the preparation of deliverable B3.1.1., where the state of the art of solar thermal power plants is given and a case study is defined.

ACTIVITY 2: *Evaluation and development of new latent heat storage systems for solar thermal plants*. The evaluation of the 100 kW_{th} latent storage prototype has been finished. From this study the following suggestions for future latent heat storage prototypes can be made:

- PCM mass should not exceed the amount that can be homogeneously melted/frozen by the tube bundle.
- Thermal insulation to environment is crucial and has to be ensured around the whole prototype.
- For a detailed description of TES module with sandwich configuration, it is necessary to improve the *quasi static* model by introducing a sensible heat term at both beginning and end of latent heat exchange regions.

Problems encountered:

ACTIVITY 1: Although there were many attendants to WG-B3 in our last meeting in Lleida, only THREE people answered to the email with B3.1.1 draft and only ONE gave me some feedback. This makes me think whether there is any real interest in what we are doing and hence in keeping this working group alive. Already at the group meeting in Lleida nobody apart from CIEMAT expressed a firm compromise of contribution since almost all institutions had "confidential agreements" and were unable to come to any commitment for sharing any results. Therefore, taking into account that the objective of SHC/ECES Tasks is working together, that in deliverable B3.1.1 there was no participation from the group members apart from me and also that to date there is not a clear definition of contributions -apart CIEMAT's-, we should decide in the next meeting in Bordeaux about the continuation of this working group in future Task 4224 meetings and if so, to find a new volunteer to lead the group.

2.14 Fraunhofer ISE, Freiburg, Germany

Scientific progress

Project: PCM Zentral. Up to now PCM was either used for heating or for cooling applications. The project “PCM-Zentral” deals with both applications with one PCM. A PCM-storage, which is installed in the country court in Düsseldorf, Germany, will be used for preheating in winter and precooling in summer. The aim of the PCM-storage is to reduce the energy demand of the air conditioning appliance of the building.

The project partners are AGN (planer), EMCO (manufacturer), BLB (building owner and user), FhG-ISE (research) and the University of Applied Sciences Münster (research).

The main application areas of the project are the definition of the PCM-storage, the system-layout and the control strategy: The plant and the data acquisition for a 3-year monitoring at the country court in Düsseldorf have to be installed. Measuring and evaluation of the PCM-storage and the material characteristics have to be taken. A simulation model for the PCM-storage will be developed.
The operation mode for preheating in winter is described in
Figure **1**. Cold ambient air either flows through an air ground heat exchanger for preheating or directly goes into the PCM-storage, depending on the temperature. Waste heat from computer systems is used to charge the PCM-storage with heat and thus preheat the ambient air. The preheated air is used for the air conditioning appliance of the building.

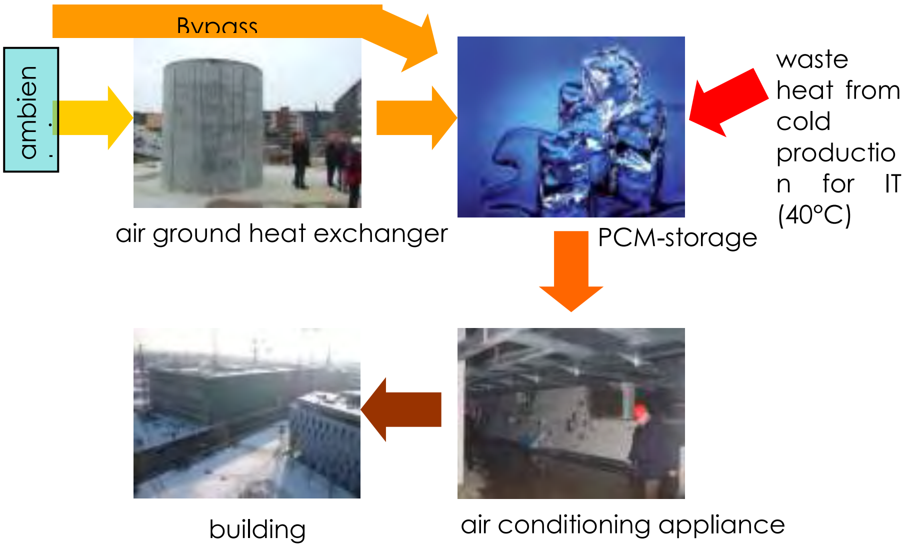


Figure 1: Operation mode for preheating in winter

In Figure 2 the operation mode for precooling in summer is described. The warm ambient air flows through an air ground heat exchanger or directly into the PCM-storage, depending on the temperature. The PCM-storage is charged with cold by air during night ventilation. The preecooled air is used in the air conditioning appliance of the building in order to cool the building.

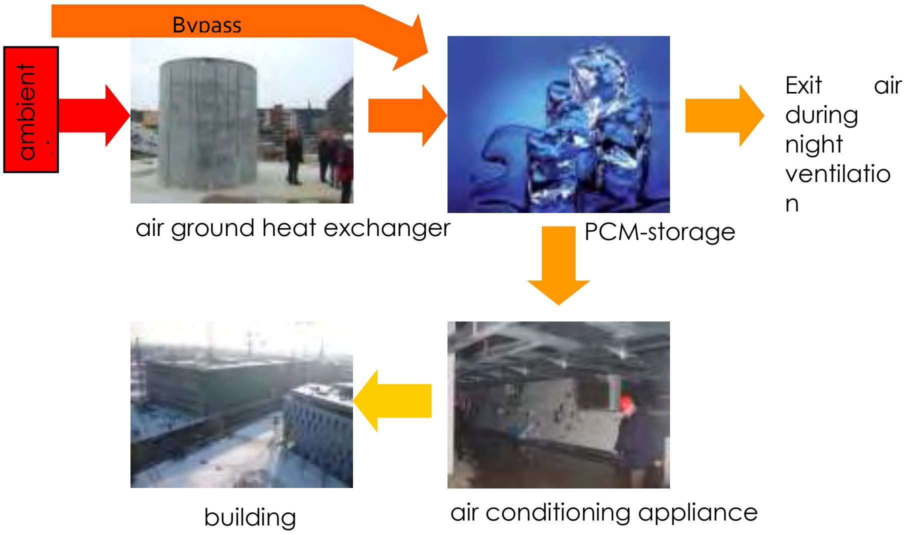


Figure 2: Operation mode for precooling in summer

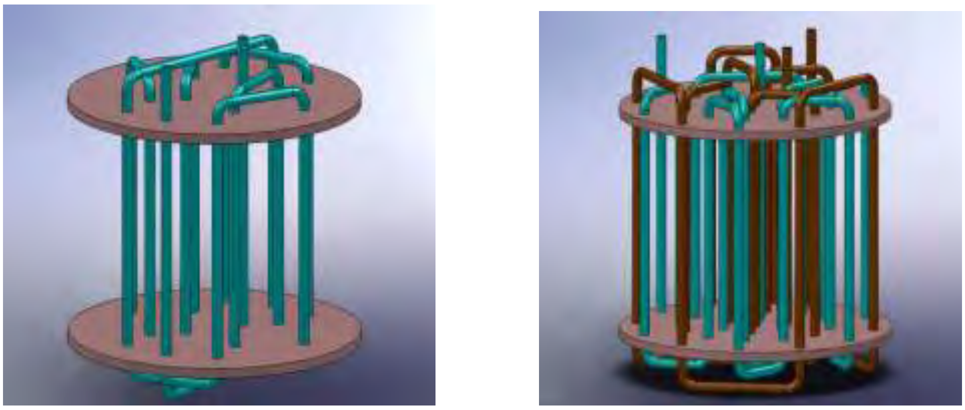
2.15 University of South Australia,

Scientific progress:

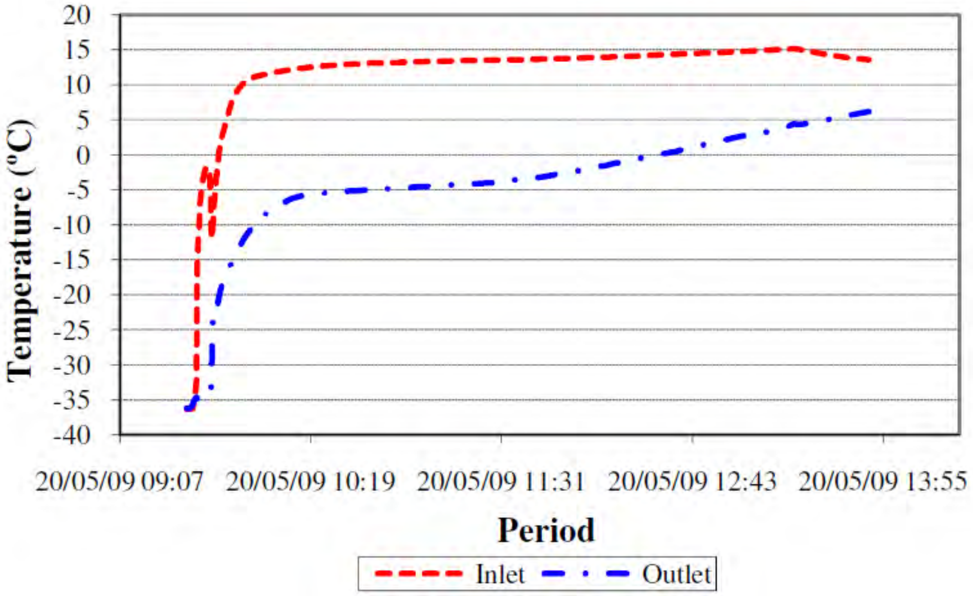
Results achieved

Experiments have been carried out. The results will be used to validate CFD models currently under development.

The first experiment (Figure below, left) was conducted with a 5.46 metres length of tube coiled in a cylindrical tank filled with -27 deg C PCM (referred to as one coil tank) while the second experiment (Figure below, right) had two coils of tubes with length of 5.61 and 6.01 metres respectively (the latter referred to as two coils tank). The compactness factor (CF) is defined as the ratio of the volume of PCM to the volume of the tank. The first experiment provides a higher CF of up to 98% but a lower heat transfer surface area. The second experiment in turn has a higher heat transfer surface area but a lower CF of 95%.



Schematic of One coil Tank (left) and Two coils Tank (right)



Melting process for the Two Coils Tank with a mass flow rate of 0.012 kg/s

2.16 Loughborough University (UK)

Project title: Thermal Conductivity Enhancement of High-Temperature Thermal Energy Stores For Use with Solar thermal Power Plants

Project short description

The proposed research aims to experimentally and numerically study the feasibility of using metal foams to enhance the heat transfer capability of phase change materials (PCMs) in high temperature thermal energy storage systems used in solar power plants. The heat transfer enhancement caused by metal foam structures will be experimentally investigated. The effect of metal foam cell size and porosity on thermal energy storage will be examined. A numerical model will be developed to predict the complicated physical phenomena during the transient charging and discharging processes. In this study, three inorganic PCMs: sodium nitrate ($NaNO_3$), potassium nitrate, and an eutectic mixture of magnesium chloride, potassium chloride and sodium chloride ($MgCl_2/KCl/NaCl$) will be employed as the latent heat storage materials. In this study, graphite foams will also be used for the experimental study, and the enhancing effect will be compared with the counterpart of metal foams

2.17 University of Ottawa (Canada)

Project title: Increasing the energy density of adsorbent materials for thermal energy storage

Project short description

A lab scale thermal energy storage system has been built using adsorption as the process for storage. This system has been used for improving the energy density of the adsorbent material and optimizing the operating conditions of the system. Different impregnation techniques has already been used and the demonstrated energy density was increased from 150 to almost 300 kWh/m^3. We are planning to carry out a numerial modelling of the system to optimize operating conditions.

2.18 University of the Basque Country (Spain)

Project title: Simulation Approach for Applicability of Phase Change Composites in Architectural Field

Project short description

Thermal storage performance of the building elements made of phase change composites mainly paraffin or salt-hydrate absorbed in porous concrete is analyzed by simulation. A mathematical model describing the energy balance of phase change storage elements allows the operational simulation and also a prediction of building storage elements applicability. The numerical calculations in function of thermophysical properties, ambient and design parameters lead to the conclusion that solidification goes fully and the heat recharging process can be used only for the case of CaCl2•6H2O composite.
The thermal simulation experience from this work would be used for prediction of the thermal performance and a choice of proper PCM composite elements for heating purposes in direct solar gain systems.

2.19 Çukurova University, Adana (Turkey)

Project title: Development of PCMs for low temperature applications

Project short description

The aim is to develop phase change materials in the temperature range of -26 ºC - +8 ºC. There are several cooling applications including air conditioning,refrigeration, transportation of temperature sensitive products within this temperature range. Thermophysical properties of the materials will be determined by DSC and temperature distribution methods. Thermal cycling, chemical stability and corrosion and material compatibility tests will be carried out. Some binary mixtures of n-alkanes within the desired temperature have been prepared and thermophysical properties have been determined. Among the mixtures prepared 80% Tetradecane - 20% Pentadecane that showed an eutectic point with melting point of 4 ºC can be of particular interest as a potential PCM for air conditioning applications. This was presented at Effstock Conference (Yilmaz et al., New Binary Alkane Mixtures As PCMs For Cooling Applications, 11th International Conference on Thermal Energy Storage- Effstock 2009 , June 14-17 2009), Currently, thermal analysis and corrosion tests are being carried out for aqueous salt solutions as PCM candidates . The first results will be published in Eurosun 2010 Conference.

2.20 INASMET – Tecnalia, San Sebastian (Spain)

Project title: ConSOLI+Da

Project short description

The main purpose of the CONSOLIDA project is the improvement of the different high concentrating solar power technologies for power generation. The critical points and the necessary technology development are identified in order to achieve a higher degree of competitiveness and capacity of penetration of these technologies in the solar market.

The ConSOLI+Da project is developed by a large consortium made up of private companies and public research institutions. The project seeks improvement of the different high-concentrating solar power technologies, progress in integrating installations, and development of more cheap and efficient applications:
- High temperature solar receivers
- Methods for producing curved mirrors
- Stirling engines
- Thermal storage systems for high temperature
- Solar cooling systems
- Solar desalination systems
- Cooling systems with less water
- Environmentally friendly heat transfer fluids
- Optimized solar-biomass hybrid plants
- Development of economically viable solar technologies for cogeneration applications

Concerning the high temperature storage systems, different available systems are studied:
1. Sensible heat solid
2. Sensible heat liquid: molten salts, synthetic and mineral oils
3. Latent Heat: phase change materials

The role of INASMET-Tecnalia in this project is mainly focused in the identification and study of the durability (corrosion, thermomechanical fatigue, creep) of metallic materials for the central tower receiver and for the TES material container, in contact with different thermal energy materials (principally molten salts).

Project title: DISTOR : Energy Storage for Direct Steam Solar Power Plants

Project short description

The main objective of the project was the development of thermal storage systems using phase change materials (PCM) in the temperature range from 230°C to 330°C for systems using steam between 30-100bar.

The specific technical targets of DISTOR to be achieved within this project were:
- To develop PCM storage materials with improved thermo-physical properties
- To select the most valuable PCM storage design for high efficient internal charging/discharging heat transfer
- To demonstrate feasibility of the developed material and storage design by on-sun testing of a 100 kW PCM storage module

The DISTOR project was dealing with the development of innovative phase change material (PCM) storage and heat transfer concepts to overcome the drawbacks of state-of-the art PCM storage technology. Alternative material and design concepts were investigated: External arrangement of PCM (Salt/Graphite composite materials and Salt-Graphite sándwich arrangement), Macro-encapsulation of PCM, and Reflux Heat Transfer Storage. To gain solar operation experience for the economic evaluation and up-scaling strategy, a 100 kW test module was built and tested on-sun under real field conditions in the DISS test facility at the Plataforma Solar de Almería, Spain. As the different concepts investigated had a varying extent of needed development effort, the100 kW module was selected as the most mature PCM concept.

The main achievements gained during of the entire DISTOR project can be summarised as follows:

- The salt system - NaNO3/KNO3 – was defined as basic PCM storage material
- Measures for improving thermal conductivity were successfully developed
- The RHTS approach was successfully tested in the lab
- The Graphite fin tube/"sandwich" design was successfully transferred into 100 kW scale
- The Graphite fin tube/"sandwich" design was proved to be useful for further scale-up and
demonstration and presents a sound basis for efficient and economic DSG storage technology

INASMET-Tecnalia role in the project was principally the definition and material selection for macroencapsulation of different PCM composite materials and the study of the compatibility (corrosion) of the metallic container materials with the different PCM formulations (molten salts with and without graphite).

2.21 Status of participation

Below is the table of participants as of June 2010.

Country	Organisation	Responsible	Funding status	IA	Person-months		part. letter
					Project	Task	
AT	IWT	Wolfgang Streicher	funded	SHC	24	6	signed
AT	AEE	Dagmar Jaehnig	funded	SHC			signed
AT	AIT	Olivier Pol	funded	SHC			signed
AT	ASIC	Bernhard Zettl	funded	SHC			signed
AU	Univ. of South Australia	Frank Bruno	funding applied for	SHC			
BE	VITO	Johan van Bael	funding applied for	ECES			
CH	EMPA	Robert Weber	funded until 2010	SHC	12	2	
CH	SPF	Elimar Frank	funding applied for	SHC			
DE	Univ. Erlangen	Jimmy Ofili	funding applied for	ECES			
DE	Fraunhofer ISE	Stefan Gschwander	funded	ECES			
DE	ITW Stuttgart	Henner Kerskes	funded	ECES	100	6	
DE	University of Kassel	Roland Heinzen	funded	ECES	48	4	
DE	Univ. of Magdeburg	Franziska Scheffler	funding applied for				
DE	Univ. Luneburg	Oliver Opel	funding applied for	ECES			
DE	Vaillant	Frank Salg	funded	ECES			
DE	ZAE Bayern	Andreas Hauer	funded	ECES	24	12	
DK	DTU	Simon Furbo	funded	SHC	15,6		signed
ES	Abengoa Solar	Cristina Prieto	funding applied for	SHC			
ES	CIEMAT	Rocio Bayon	funded	SHC	56		
ES	Inasmet	Patricio Aguirre	funding applied for	SHC			
ES	Tekniker	Miren Blanco	funded	SHC			
ES	University of Lleida	Lluisa Cabeza	funded	ECES			
ES	University of Zaragoza	Ana Lázaro	funded	SHC	19,7	1,15	
FR	EDF	Philippe Stevens	funded		48	8	
FR	INES	Philippe Papillon	funded				
FR	Université de Bordeaux	Elena Palomo	funded				
FR	Université de Lyon	Frédéric Kuznik	funded				
FR	Université de Savoie	Lingai Luo	funded		40	2	
NL	ECN	Martijn van Essen	funded	SHC	48	24	
NL	Eindhoven Univ. of Technology	Camilo Rindt	funded	SHC	52		
SE	Ecostorage/KTH	Viktoria Martin	funded	ECES	48	8	
SI	National Institute of Chemistry	Venceslav Kaucic	funding applied for				
TR	Cukurova University	Halime Paksoy	funding applied for	ECES			
TR	Gaziosmanpa Univ.	Cemil Alkan					
UK	University of Loughborough	Philip Eames	funding applied for				
UK	University of Warwick	Chang-Ying Zhao	funded		100		
US	Oak Ridge National Laboratory	Jan Kosny	funded	SHC			
US	University of Minnesota	Jane Davidson	funded	SHC			signed
			Total		**651,3**	**73,15**	

Changes with respect to the participant list of November 2009:
A new contact person for Vaillant and renewed interest in the Task from this company
BASF UK (the former CIBA Geigy) withdrew from the Task. Discussion with BASF Future Business are ongoing.

It is foreseen that EMPA will establish a follow-up project together with SPF Rapperswil in fall 2010.

The following organisations showed interest in joining:
University of Auckland (New Zealand). They attended the Lleida meeting.
University of Mons and University of Liege (Belgium), they will attend the Bordeaux meeting.
Ciatesa (Italy)
University of Palermo (Italy).

The participation level of the organisations is not complete yet. Participation can be through either the ECES or the SHC programme, both are included. Not all the participants have been drawn under one programme yet, especially the French organisations.
Both Slovenia and the United Kingdom do not participate in the IEA SHC or ECES Implementing Agreement. The University of Loughborough and other organisations are undertaking action to get the UK join the SHC Implementing Agreement. The spring expert meeting in 2011 is planned in Belfast. This could help to convince UK policy makers.
The SHC national participation letters for this Task have been sent out in April 2009. Seven organisations returned the signed letter.

2.22 Deliverables

No final deliverables were produced in the reporting period. Some concepts were completed:
CIEMAT: Deliverable B3.1.1 for IEA-SHC Task 42/24.
Case study: Solar Power Plants
Concept ready: February 2010
AIDICO: final concept of report: State of the art of encapsulation of inorganic PCM

2.23 Information and Publication

Presentations about the Task4224 and its work have been given at:

RHC-ETP Conference, Bilbao, Spain, February 2010
World Sustainable Energy Days, Solar Thermal Conference, Wels, Austria, February 2010.
CIMTEC 2010, Fifth Forum on New Materials, Montacatini Terme, Italy, June 2010

Reports:

V.M. van Essen, L.P.J. Bleijendaal, J. Cot Gores and P.W. Bach, (2009), Development of a proof-of-principle thermochemical reactor for the built environment, confidential memo, ECN-EI-2009-410

H.A. Zondag, P.W. Bach and V.M. van Essen, Techno-economical analysis TC storage (2009), confidential report, ECN X-09-154

Preliminary study on thermochemical heat storage materials, Eldhose Iype, WET 2010, internal report TU/e

VITO: Final report of the strategic research on thermal energy storage – programme 2009, February 2010

CIEMAT: A confidential internal report has been written about the evaluation of the 100 kW_{th} latent storage prototype experimental results. A publishable version of it has been submitted to an international journal.

Papers submitted:

Characterization of melting and solidification in a real scale PCM-air heat exchanger. Experimental results and empirical model.
P. Dolado, A. Lazaro, J.M. Marin, B. Zalba, Energy Conversion and Management, submitted in December 2009.

Characterization of melting and solidification in a real scale PCM-air heat exchanger. Numerical model and experimental validation.
P. Dolado, A. Lazaro, J.M. Marin, B. Zalba, Energy Conversion and Management, submitted in February 2010.
V.M. van Essen, L.P.J. Bleijendaal, B.W.J. Kikkert, H.A. Zondag, M. Bakker, and P.W. Bach, **development of a compact heat storage system based on salt hydrates**, Eurosun 2010 conference, Graz, Austria (submitted)

V.M. van Essen, H.A. Zondag, L.P.J. Bleijendaal, B.W.J. Kikkert and M. Bakker, **application of $MgCl_2.6H_2O$ for thermochemical seasonal solar heat storage**, IRES V, Berlin, Germany (submitted)

Quinnell, J. A., Davidson, J. H., Burch, J., "Liquid Calcium Chloride Storage: Concept and Analysis," *Journal of Solar Energy Engineering (submitted)*

Papers accepted:

Towards seasonal heat storage based on stable super cooling of sodium acetate trihydrate
Simon Furbo, DTU. Accepted for EuroSun 2010 Congress.

Looking for "low cost" Phase Change Materials and their application for energy saving.
Peñalosa, C., Lazaro, A., Delgado, M., Zalba, B. 2010, Paper accepted for inclusion in the EuroSun 2010 conference proceedings, Graz (Austria), 28 September - 1 October 2010.

Experimental study of the heat transfer in a microencapsulated PCM slurry.
M. Delgado, J. Mazo, C. Peñalosa, A. Lázaro, B. Zalba. Paper accepted for the 9th IIR Conference on Phase-Change Materials and Slurries for Refrigeration and Air Conditioning, Sofia (Bulgaria), 29 September - 1 October 2010.

Analysis of the experimental behaviour of a 100 kW_{th} latent heat storage system for direct steam generation in solar thermal power plants, Rocío Bayón*, Esther

Rojas, Loreto Valenzuela, Eduardo Zarza and Javier León, Applied Thermal Engineering 2010 (accepted)

Jan Kośny, David Yarbrough, Phil Childs, Som Shrestha, William Miller, Jerry Atchley, Marcus Bianchi, John Smith, Tom Fellinger, Elizabeth Kossecka, Edwin Lee **– "Theoretical and Experimental Thermal Performance Analysis of Building Shell Components Containing Blown Fiber Glass Insulation Enhanced with Phase Change Material (PCM)"** – accepted for XI Thermal Envelopes Conference, Clearwater FL, Dec. 2010.

Jan Kosny, Therese Stovall, and David Yarbrough – **"Theoretical and Experimental Thermal Performance Analysis of Complex Thermal Storage Membrane Containing Bio-Based Phase Change Material (PCM) "** – accepted for XI Thermal Envelopes Conference, Clearwater FL, Dec. 2010.

E. Kossecka, J. Kośny – "**Thermal Balance of a Wall with PCM-Enhanced Thermal Insulation**" – accepted for CESBP 2010 conference, Krakow, Poland, Sept. 2010

N.H.S. Tay, F. Bruno, M. Belusko, **Experimental Investigation of Heat Transfer Tubes in a Phase Change Thermal Energy Storage System**, Proceedings of the 9th IIR Gustav Lorentzen Conference on Natural Working Fluids, 11-14 April 2010, Sydney.

N.H.S. Tay, M. Belusko, F. Bruno, **Experimental Investigation of Coils in a Phase Change Thermal Energy Storage System**, International Conference on Applied Energy (ICAE), ICAE2010, Singapore, 2010.

Papers published:

Multi-functional building products based on natural stone and PCMs with stabilised thermal and dynamic load.
M. Founti, I. Mandilaras, K. Laskaridis, M. Patronis, M.D. Romero-Sánchez, A.M. López-Buendía, 7th Conference on Phase Change Materials and Slurries for refrigeration and Air Conditioning. Dinan, France. 13-15 Sept. 2006. pp.201-212

THERMAL ENERGY STORAGE IN PCM TREATED NATURAL STONE
M.D. Romero Sánchez, M. Founti, C. Guillem López, A. M. López Buendía
Effstock 2009. Thermal Energy Storage for Efficiency and Sustainability. 11th International Conference on Thermal Energy Storage. Estocolmo-Sweden. 14-17th June 2009

PHASE CHANGE MATERIALS (PCM) AS THERMAL ENERGY STORAGE INCORPORATED TO NATURAL STONE
M.D. Romero Sánchez, Noelia Baeza, J.M. Cuevas, C. Guillem López, A.M. López Buendía
Global Stone Congress 2010. Alicante. Spain. 2-5th march 2010

PHASE CHANGE MATERIALS (PCM)- TREATED NATURAL STONE FOR THERMAL ENERGY STORAGE IN BUILDINGS: INFLUENCE OF PCM MELTING TEMPERATURE
M.D. Romero Sánchez, J.M. Rodes, C. Guillem López, A.M. López Buendía
CIB World Congress 2010. Salford. United Kingdom. 10-13th may 2010. pp341.

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THERMAL ENERGY STORAGE IN NATURAL STONE TREATED WITH PCMs
M.D. Romero Sánchez, A.M. López Buendía, M. Stamatiadou, D. Katsourinis, M. Founti
CIB World Congress 2010. Salford. United Kingdom. 10-13th may 2010. pp344.

State of the art on high temperature thermal energy storage for power generation. Part 1 - Concepts, materials and modellization.
Antoni Gil, Marc Medrano, Ingrid Martorell, Ana Lázaro, Pablo Dolado, Belén Zalba, Luisa F. Cabeza. Renewable and Sustainable Energy Reviews, Volume 14, Issue 1, January 2010, Pages 31-55.

[1] N'Tsoukpoe K. E., Liu H., Le Pierrès N., Luo L., **A review on long-term sorption storage**, Renewable and Sustainable Energy Reviews 13 (9), p. 2385–2396, December 2009.

[2] Le Pierrès N., Luo L., **Chemical interseasonal solar heat storage**, Forum Applying Energy Storage in the Buildings of the future, annexe 23 IEA ECES, INSA de Lyon (France), 8 March 2010.

[3] N'Tsoukpoe K. E., Le Pierrès N., Luo L., **Stockage de chaleur solaire à long terme**, CIFEM 2010 (Colloque International Francophone d'Energétique et Mécanique), Saly (Sénégal), 16-20 may 2010.

[4] Le Pierrès N., Luo L., N'Tsoukpoe K. E., Mangin D., Fan L., Marty P., Marvillet C., Paulus C., Lancereau P., **Procédé de stockage intersaisonnier de chaleur solaire pour le chauffage du bâtiment par procédé à absorption LiBr-H2O**, congrès français de thermique (SFT 2010), 25-28 may 2010, Le Touquet (France).

[5] N'Tsoukpoe K. E., Le Pierrès N., Luo L., **Stockage de chaleur solaire par sorption : Analyse et contrôle du système à partir de sa simulation dynamique**, congrès français de thermique (SFT 2010), 25-28 mai 2010, Le Touquet (France).

V.M. van Essen, H.A. Zondag, J. Cot Gores, L.P.J. Bleijendaal, M. Bakker, R. Schuitema, W.G.J. van Helden, Z. He, C.C.M. Rindt, **Characterization of MgSO4 Hydrate for thermochemical Seasonal Heat Storage,** J. Sol. Energy Engineering, **131**(4), 041014, (Nov 2009)

Quinnell, J. A., Davidson, J. H., Burch, J., "Liquid Calcium Chloride Storage: Concept and Analysis," *ASME 2010 4th Annual Energy Sustainability Conference*, May 17-22, Phoenix, AZ.

2.24 Other organisational matters

There is a PhD vacancy at the Eindhoven University of Technology, for the granted project “Development of micro- and meso-scale models for heat and vapor transport in storage materials”.

Task Time Plan

The task start date is 1 January 2009 and the end date is 31 December 2012.

	2009				2010				2011				2012			
Working Group	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
A1 Materials engineering and processing				A1.1				A1.2 A1.4				A1.3 A1.5				
A2 Tests and characterisation					A2.1	A2.2						A2.3			A2.4	
A3 Numerical modelling				A3.1		A3.2				A3.3						A3.4 A3.5
A4 Apparatus and Components						A4.1						A4.2 A4.3				
B3 High temperature					B3.1.1		B3.1.2			B3.1.3				B3.2 B3.3 B3.4		B4
C1 Theoretical limits					C1.1			C1.2				C1.3				
C2 System integration				C2.1				C2.2				C2.3				
Task meetings	●		●		●		●		●		●		●		●	

The task time plan will be updated after the Bordeaux expert meeting in July 2010.

3 Issues for the Executive Committee

No issues for the ExCo.

Anhang 8:

Präsentation Basciotti (AIT), Why Thermochemical Storage for District Heating? Lleida Meeting

IEA-Task 42
Compact Thermal Energy Storage

AIT, Energy Department, SBT
23-25.09.09
Daniele BASCIOTTI, Olivier POL

Target of activities

- Simulation supported analysis of the technical potential for using small scale sorption storage units in combination with **district heating** for **cooling** applications:
  - Impact on the **operation** of the district heating network
  - Load management aspects:
    - Charging and discharging time
    - Supply / demand balance (sizing of the storage unit? cooling load covered?)
  - Energy performance assessment of the **entire** system (DH+storage) and comparison with using decentral absorption chillers
- Main contribution in **Subtask B** (system integration and applications: district heating and use for cooling)

Why using TCS in combination with district heating?

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY TOMORROW TODAY

- **Limitations** using distributed **small-sized absorption chillers** (AbC) in existing district heating networks described and assessed in completed research project [Sager, 1998], [Sager, 2004], [Pol, 2008]
- **Main problem** → **return temperature increase** due to operation of chillers, when the heating load for the AbC is higher then the total load of the other consumer substations
- **Possible solutions** → Combine AbC with processes with **higher temperature drop** on the district heating side or **necessity of storage and load management**
    1. Processes with a higher temperature drop is not only a technical issue (it depends on the strategy of the DH company in relation with such potential consumers)
    2. Additional storage equipment would lead to additional costs which are not acceptable because of the already limited economical feasibility of AbC in combination with DH
- **Outcome of the research project** in Mureck [Pol, 2008] was to look for:
    - Systems integrating **storage features** in their design
    - **Desiccant** and **Evaporative Cooling systems**, which have lower driving temperatures in comparison with AbC
    - Integration of **solar thermal panels** (in combination with solar cooling), as long as this doesn't lead to an excess of heat in the summer months

Working Plan

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY TOMORROW TODAY

- Modelling of sorption storage units
    - Literature **search: done**
    - Scale **definition** for modelling: **done**
    - Model **implementation** in Dymola/Modelica: **ongoing**
- Model **validation**: review / information exchange with Task experts, partecipation in WGA3 (Numerical Modelling)
- **Integration** in a district heating network model already validated of Mureck, Austria: definition of control strategies
- Sensitivity analysis (size, position and number of storage units)
- Energy performance assessment (for the entire system)
- Comparison with a situation with absorption chillers connected to the district heating (theoretical case study in Mureck, Austria)

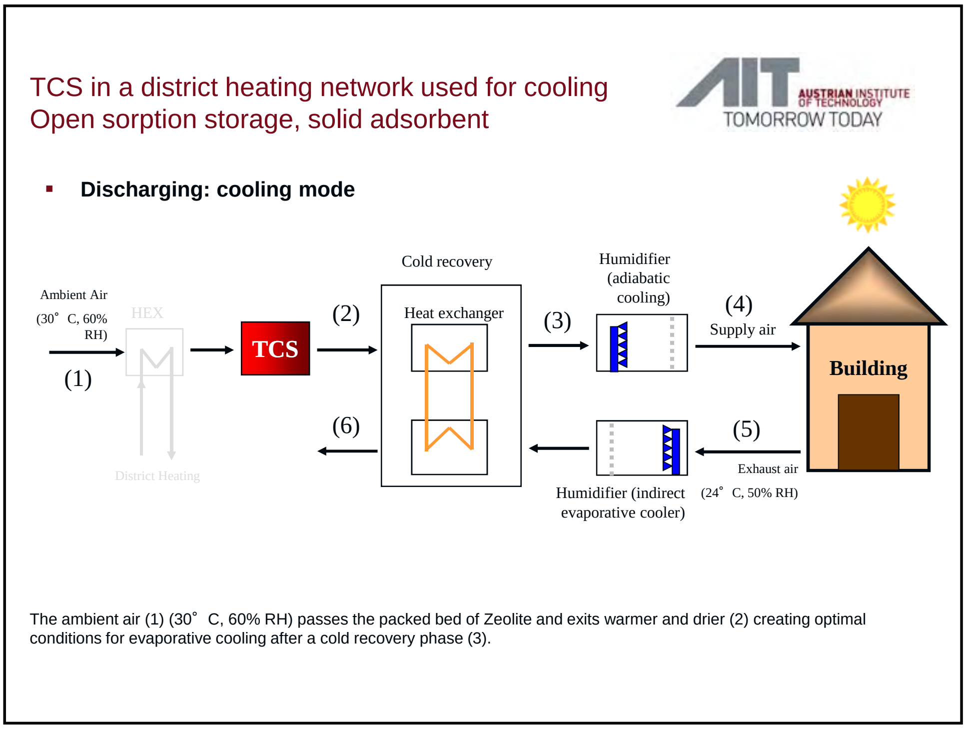
TCS – Thermo Chemical Storage and use for cooling

- The TCS can be divided into:
    - **Open** sorption storage systems (the air to be conditioned is in direct contact with the sorption material)
    - **Closed** sorption storage systems (cooling distribution through a cold water network)
- Materials for thermochemical storage system can be:
    - Packet bed or rotary wheel of **solid** adsorbents (e.g., silicagel, zeolite)
    - **Liquid** desiccant (e.g., Lithium Chloride) (with the same physical principle as in an absorption chiller)

TCS in a district heating network

Real cases using solid adsorbent and liquid absorbent

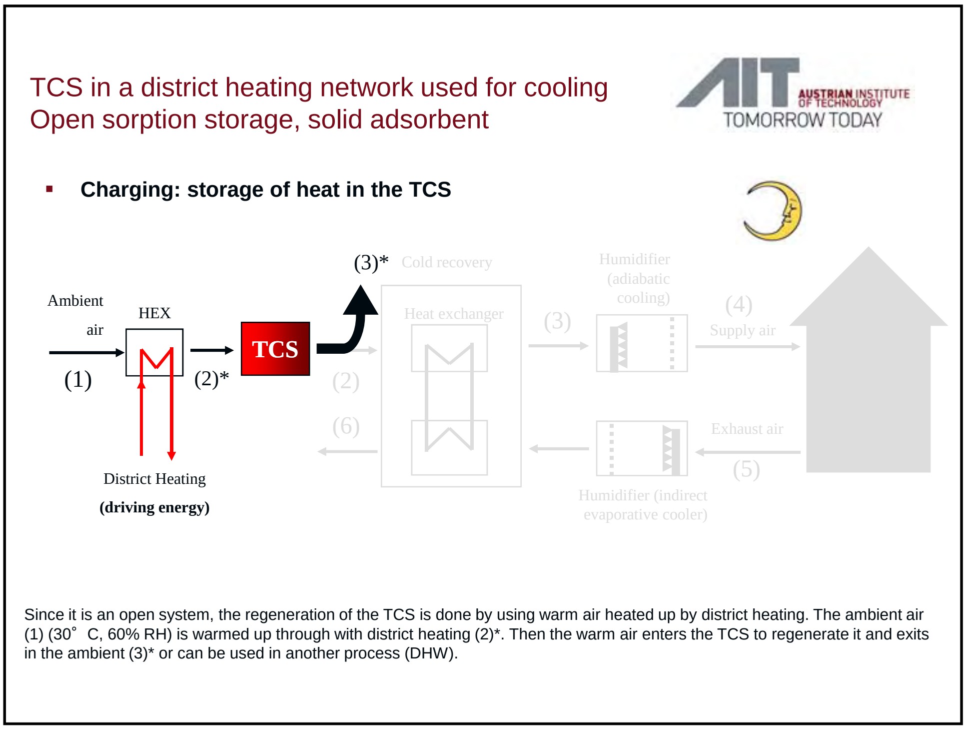
- Munich (Germany) – Jazz club (1997) [Hauer, 2007]
    - Mass of adsorbent: 7000 kg of Zeolite 13X as storage tank (three horizontal cylinders connected)
    - Max air flow: 6000 m^3/h
    - Max cooling power: 50 kW
    - Energy density (cooling): Up to 100 kWh/m^3
        - Findings/Feedback from operation?
- Amberg (Germany) – Office Building (2003) [Hauer, 2007]
    - Mass of absorbent: 3000 kg of Lithium Chloride (2 separated tanks of 12m^3 to store diluited and concentrated solution)
    - Max air flow: 30.000 m^3/h
    - Max cooling power: 150 kW
    - Cooling and dehumidification energy per year: 20 MWh
    - No experimental results known
        - Corrosion problems?



TCS in a district heating network used for cooling
Open sorption storage, solid adsorbent

- **Discharging: cooling mode**

The ambient air (1) (30° C, 60% RH) passes the packed bed of Zeolite and exits warmer and drier (2) creating optimal conditions for evaporative cooling after a cold recovery phase (3).



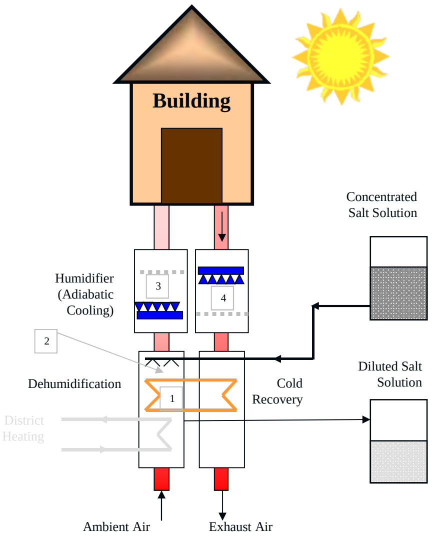
TCS in a district heating network used for cooling
Open sorption storage, solid adsorbent

- **Charging: storage of heat in the TCS**

Since it is an open system, the regeneration of the TCS is done by using warm air heated up by district heating. The ambient air (1) (30° C, 60% RH) is warmed up through with district heating (2)*. Then the warm air enters the TCS to regenerate it and exits in the ambient (3)* or can be used in another process (DHW).

TCS in a district heating network used for cooling
Open sorption storage, liquid absorbent

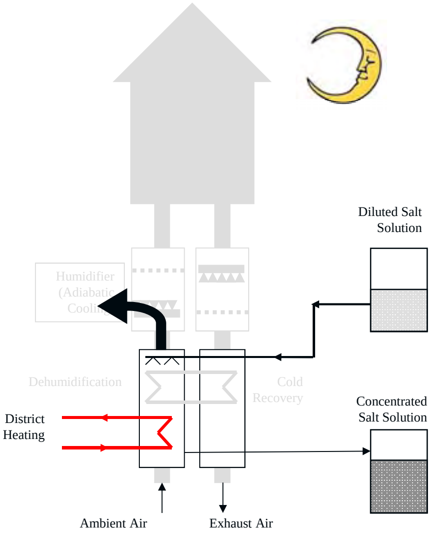
- Discharging: cooling mode



The ambient air is cooled down by the sequence of an adiabatic cooling process (3) after dehumidification using the concentrated salt solution (2), and by cold recovery (1) done through a heat exchanger connected to the return air cooled down until saturation (indirect evaporating cooling)

TCS in a district heating network used for cooling
Open sorption storage, liquid absorbent

- Charging: storage of heat in the TCS



Regeneration is possible at temperatures above 60° C which is possible by connecting it to the district heating network during night time.

Thank you for your attention!

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Anhang 9:

Präsentation Heinz (IWT),

Simulation results of PCM Seasonal storage,

Bordeaux Meeting

IEA Task42/Annex44
Bordeaux, 08.07.2010

TES with PCM for Solar Combisystems Preliminary Results

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Institut für Wärmetechnik
Technische Universität Graz
andreas.heinz@tugraz.at
http://www.iwt.tugraz.at

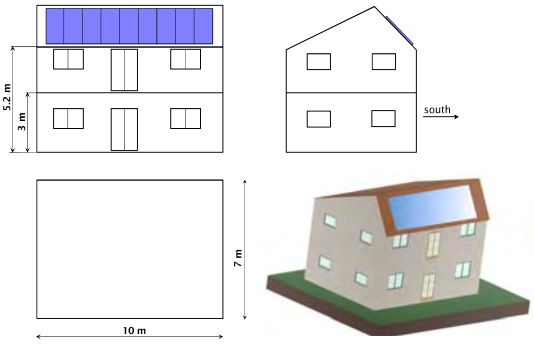
FFG
bmvit
Bundesministerium für Verkehr, Innovation und Technologie

Overview

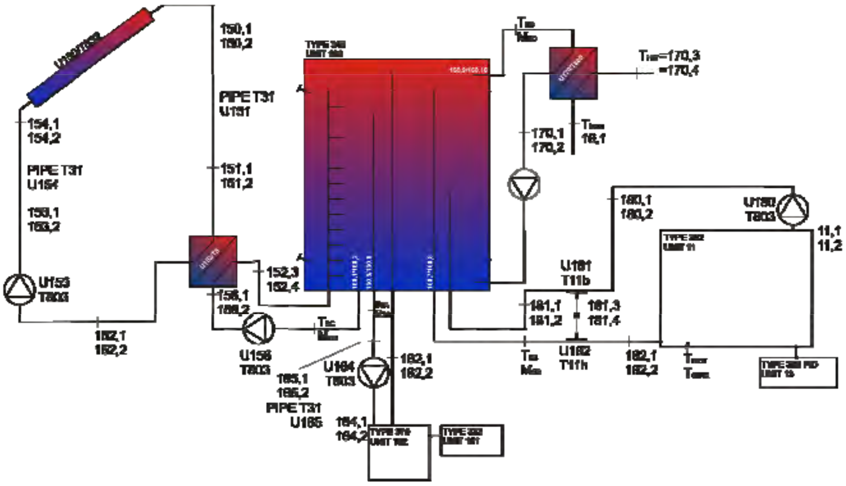
- Analysis of an integration of PCM modules into a solar combistore
- reference solar combisystem and reference building from IEA SHC Task 32 is used
- different configurations of collector area, storage volume
- Different PCM configurations:
  - PCM fraction
  - thermal properties (real and fictive materials):
    - melting temperature
    - latent heat

Reference building (Task 32)

- useful floor area ***140 m²***
- ***3,3 kW*** design heat load
- low energy building (heating demand: ***30 kWh/m²a***)
- floor heating system (flow/return temperature: 35/30 °C @ T_{amb} -12 °C)
- DHW demand: ***~ 3000 kWh/a***
- climate of Graz

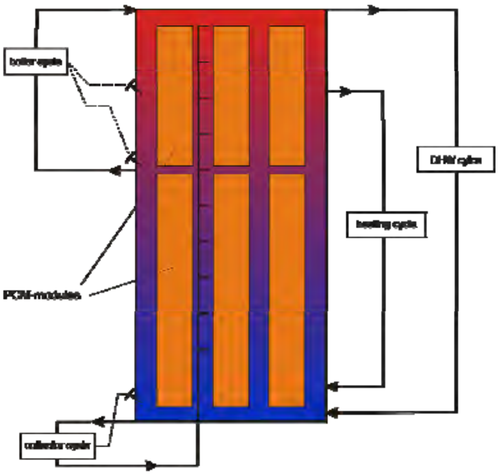


Reference system (Task 32)



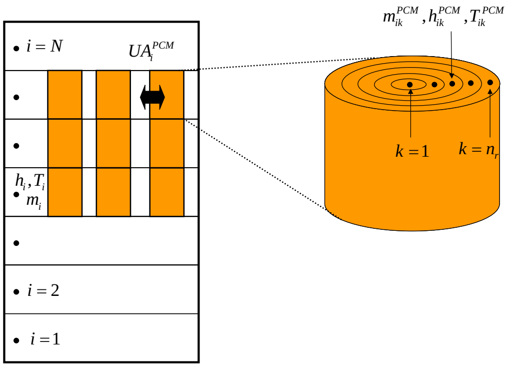
Storage tank: configuration with PCM modules

- Cylindrical PCM modules
- Module diameter 75 mm
- PCM volume fraction 50%
- Conduction in radial direction not considered

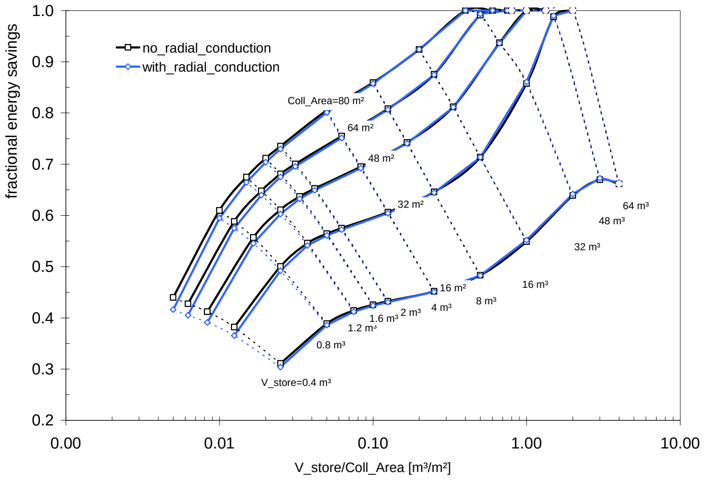


Storage tank model: TRNSYS Type 840

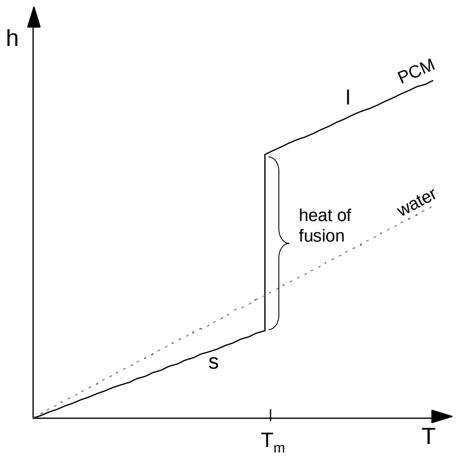
- developed within IEA SHC Task 32
- different geometries of PCM modules (cylinders, spheres, plates)
- 1-dimensional heat transfer in water volume
- 2-dimensional heat transfer (conduction only) within PCM modules
- validated with measurements



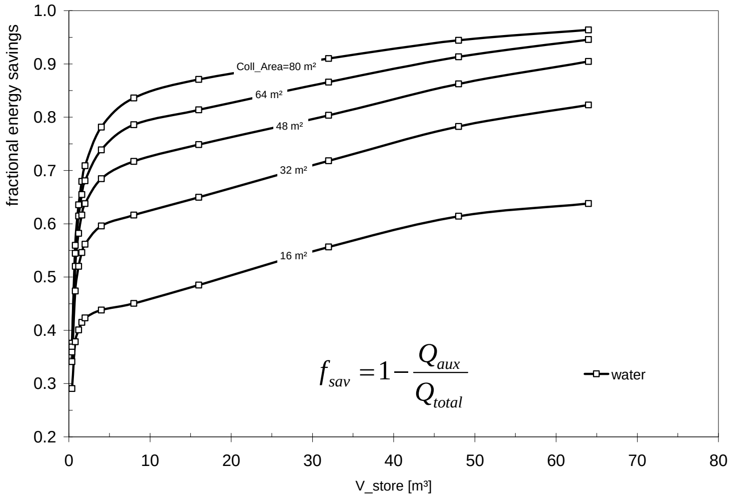
Influence of the consideration of the conduction in radial direction



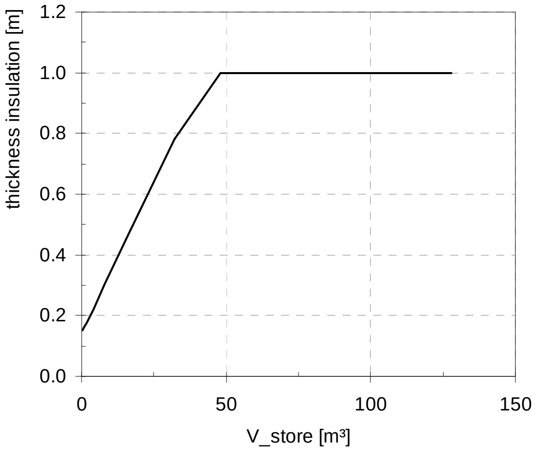
Thermal properties of PCM

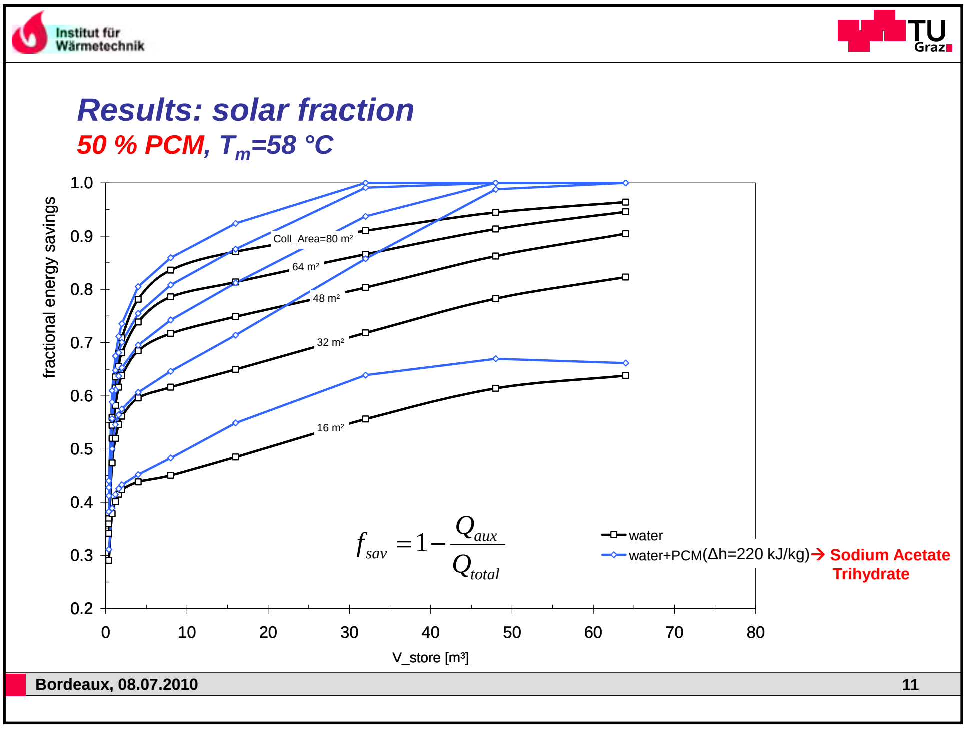


Results: solar fraction



Thickness of storage insulation





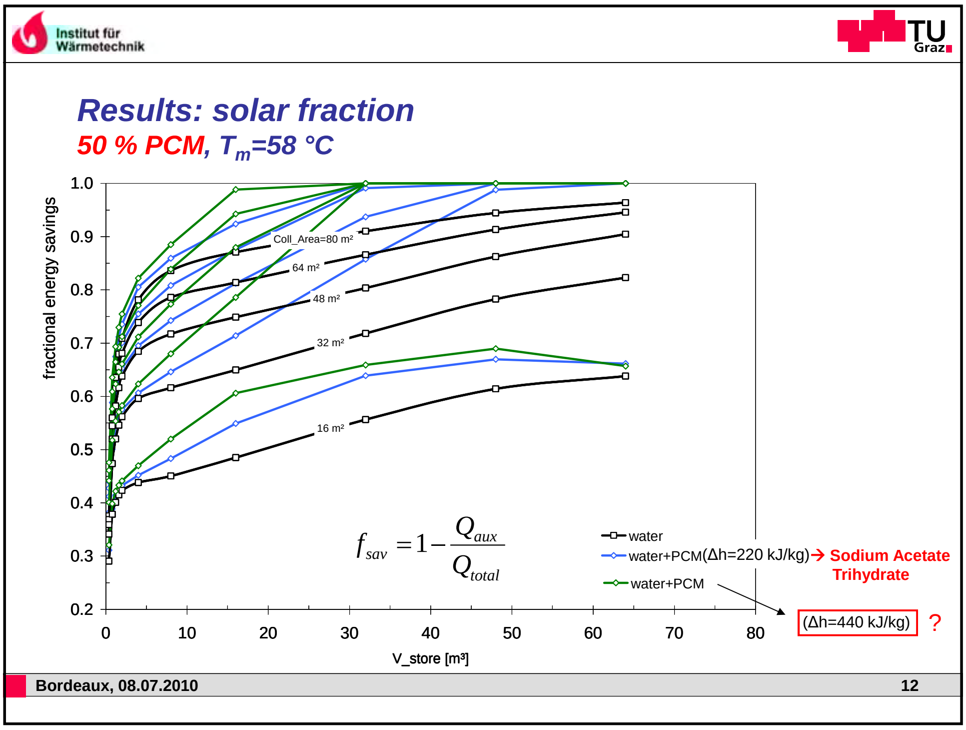
Results: solar fraction

50 % PCM, T_m=58 °C

$$f_{sav} = 1 - \frac{Q_{aux}}{Q_{total}}$$

- water
- water+PCM(Δh=220 kJ/kg) → **Sodium Acetate Trihydrate**

Bordeaux, 08.07.2010 **11**



Results: solar fraction

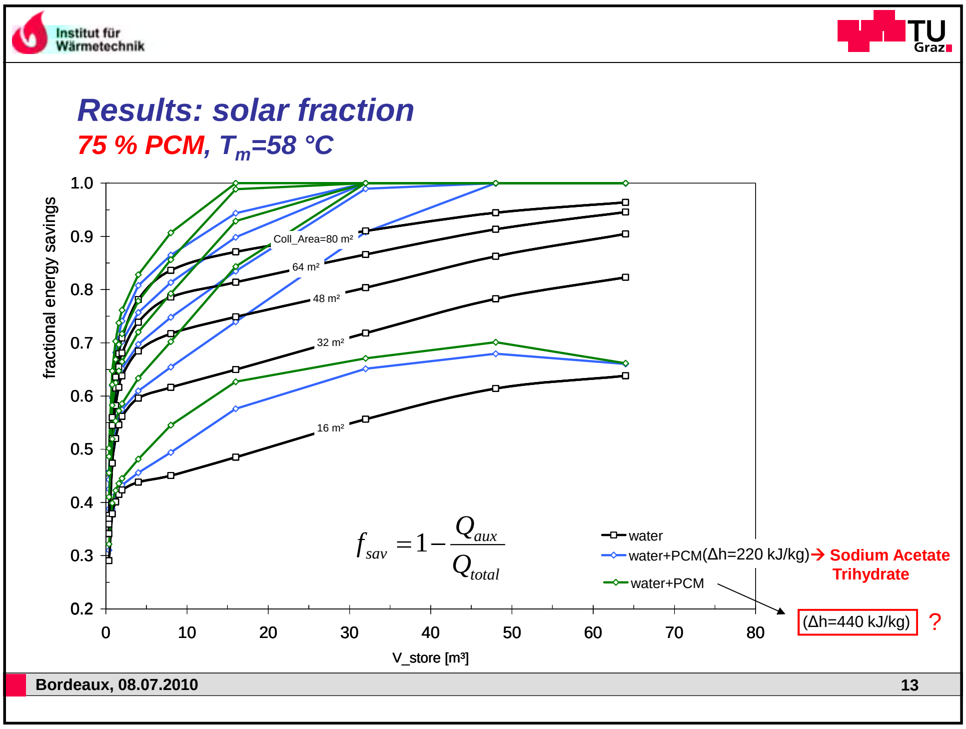
50 % PCM, T_m=58 °C

$$f_{sav} = 1 - \frac{Q_{aux}}{Q_{total}}$$

- water
- water+PCM(Δh=220 kJ/kg) → **Sodium Acetate Trihydrate**
- water+PCM

(Δh=440 kJ/kg) ?

Bordeaux, 08.07.2010 **12**



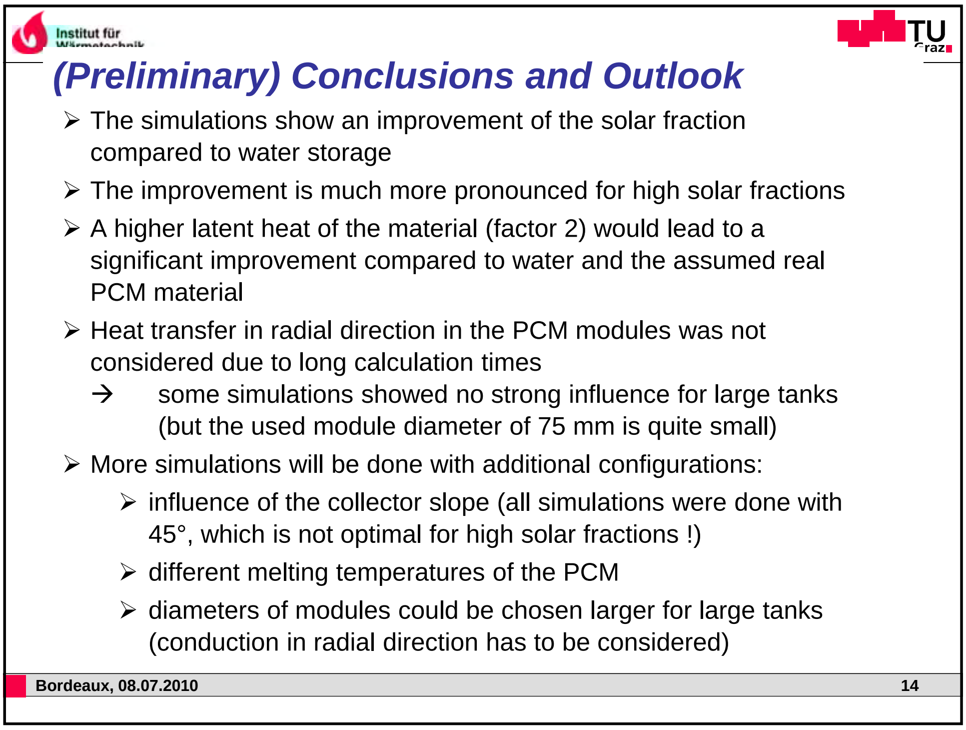
Results: solar fraction

75 % PCM, T_m=58 °C

$$f_{sav} = 1 - \frac{Q_{aux}}{Q_{total}}$$

→ **Sodium Acetate Trihydrate**

(Δh=440 kJ/kg) ?



(Preliminary) Conclusions and Outlook

- The simulations show an improvement of the solar fraction compared to water storage
- The improvement is much more pronounced for high solar fractions
- A higher latent heat of the material (factor 2) would lead to a significant improvement compared to water and the assumed real PCM material
- Heat transfer in radial direction in the PCM modules was not considered due to long calculation times
  → some simulations showed no strong influence for large tanks (but the used module diameter of 75 mm is quite small)
- More simulations will be done with additional configurations:
  - influence of the collector slope (all simulations were done with 45°, which is not optimal for high solar fractions !)
  - different melting temperatures of the PCM
  - diameters of modules could be chosen larger for large tanks (conduction in radial direction has to be considered)

Question

What is the maximum latent heat that is theoretically possible for a PCM

?

Hg: -40°C (160 kJ/l) …… ??? ……. Fe: 1500°C (2000 kJ/l)

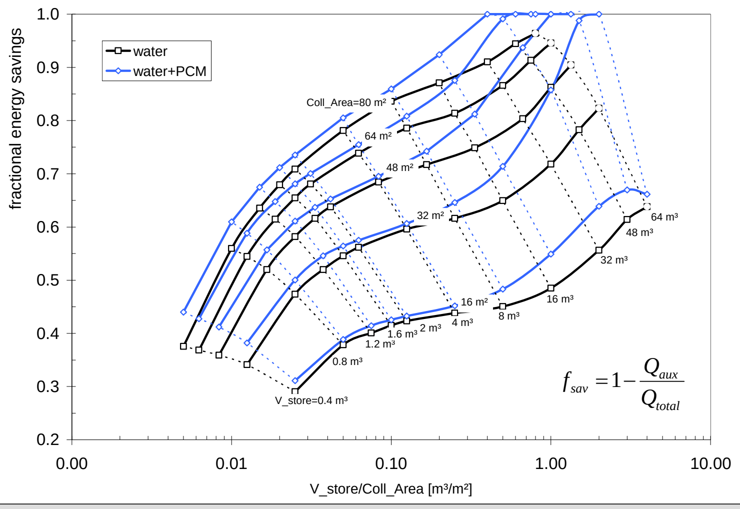
Thank you and regards from Graz !

ACKNOWLEDGEMENT:
This project is carried out in the framework of the Austrian participation in the Energy Technology Programme of the IEA and funded by the Austrian Ministry for Transport, Innovation and Technology

FFG

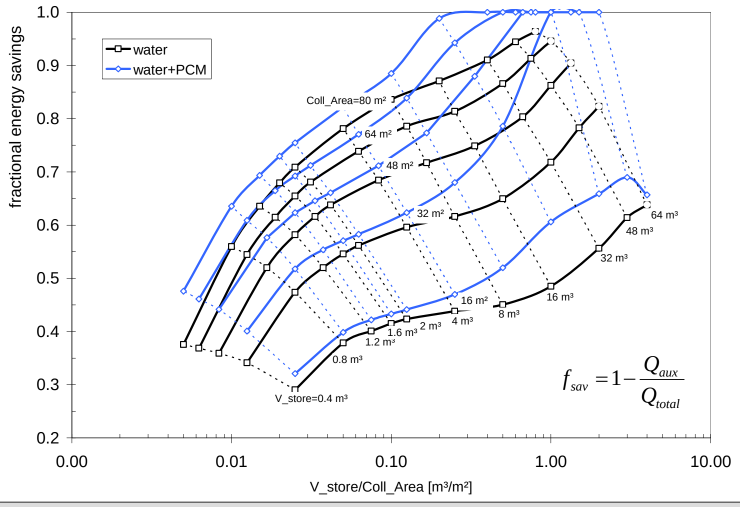
bmvit
Bundesministerium für Verkehr, Innovation und Technologie

Results: Δh=220 kJ/kg

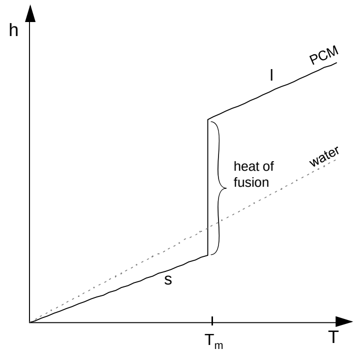


$$f_{sav} = 1 - \frac{Q_{aux}}{Q_{total}}$$

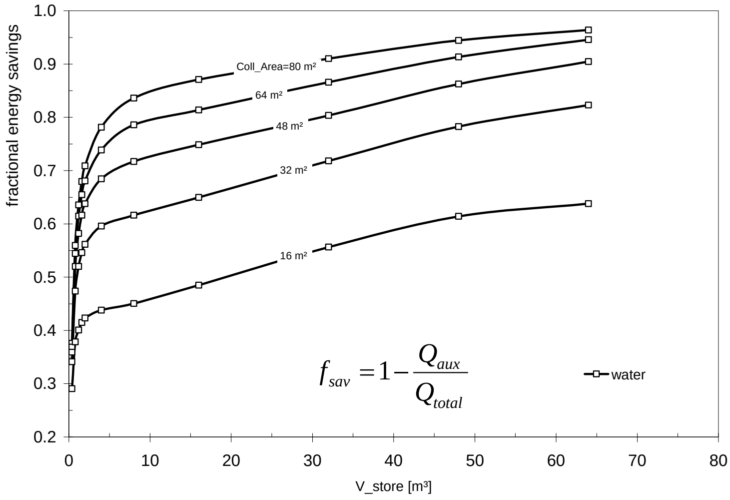
Results: Δh=440 kJ/kg



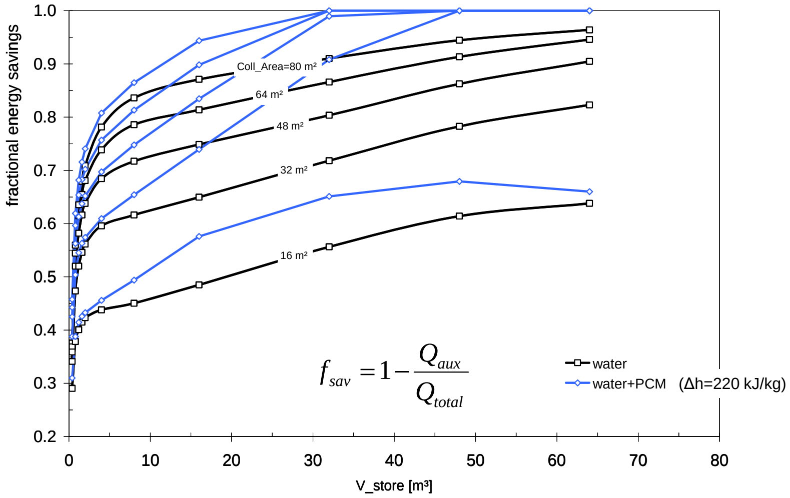
$$f_{sav} = 1 - \frac{Q_{aux}}{Q_{total}}$$



Results: solar fraction



Results: solar fraction (PCM volume fraction 75%)



$$f_{sav} = 1 - \frac{Q_{aux}}{Q_{total}}$$

Anhang 10:

Bericht des AIT über die Koppelung von thermochemischen Speichern mit Nahwärmenetzen.

IEA SHC/ECES TASK/ANNEX 4224

Compact Thermal Energy Storage: Material Development for System Integration –

Teilnahme und Mitarbeit an der Task Definition Phase und Startphase des Joint IEA-SHC Task 42 " ADVANCED MATERIALS FOR COMPACT THERMAL ENERGY STORAGE"

1. Endbericht – Anhang 10

Austrian Institute of Technology
Energy Department
Business Unit Sustainable Building Technologies
Daniele Basciotti and Olivier Pol

Projekt im Rahmen der österreichischen Beteiligung am Energietechnologieprogramm der IEA. Im Auftrag des Bundesministeriums für Verkehr Innovation und Technologie.

Contents

I.1 Executive summary

If absorption chillers (AbC) are connected to district heating (DH) networks, the rather low temperature drops on the generator side (below 10 K) leads to an increase of the return temperature in the DH network, thus limiting the number of chillers which can be operated simultaneously. This problem may occur when heating loads for the AbC are higher than total loads from other conventional consumer substations. As desiccant cooling systems (DEC) work with higher temperature drops on the heating side and thus maintain the return temperature of DH network at low levels, they can be more easily integrated in DH networks than AbC. The target of the simulation project is therefore to assess the performance of DH networks integrating DEC systems realised as Thermo Chemical Storage units (TCS) and compare it to using decentralised small-sized AbC.

An overview of different existing technical solutions for using TCS in DH networks is carried out first together with a presentation of the state of the art of computational models for TCS and DH available in literature. An open solid adsorbent configuration is then selected as combined desiccant cooling system and sorption storage. Modelica/Dymola is chosen as simulation tool for both the DEC system and the network simulation.

Three different indicators (distribution losses, maximum return temperature, average temperature drop between supply and return line) are defined to evaluate the performance of the proposed DH network integrating DEC systems and compare it with a situation when AbC are connected. By considering the simulation results of a theoretical case study, a sensible reduction of the share of distribution losses in the DH network can be noticed, resulting from an increased use of the DH network (advantage obtained also by using AbC). Moreover, recommendations on the preferred temperature drops of the heating coil in the DEC system are formulated as result from a sensitivity analysis. However, additional investigations are necessary to derive an optimised control strategy in the charging phase of the storage.

As a main conclusion, there is no limitation in terms of cooling power installed. In fact by using a DEC system, the return line temperature can be reduced in many hours, due to the high temperature drop allowed by the heating coils (in the selected cases a maximum reduction of 2K can be achieved).

A primary energy assessment shows a reduction of primary energy use up to 90% compared to traditional air conditioners. This can be achieved by using a DEC system in combination with a DH network using geothermal energy as source.

I.2 Introduction

The increasing peak electricity demand, partly caused by the operation of electric driven air conditioning, can be reduced by using thermally driven cooling processes. A possibility for improving the overall efficiency of thermally driven cooling processes in combination with renewable energy sources is to use thermal energy storage (TES). By improving the storage capacity of TES, the degree of utilisation of renewable energy sources can be increased. This is valid both for decentralised applications (like solar cooling systems for single buildings) and for large scale network applications (distributed thermal driven cooling units connected to a district heating network).

In combination with a thermally driven cooling process, TES can be included on the heating side, on the cooling side or on both sides simultaneously. Storage on the heating side would consist in including a hot water tank on the generator side of an absorption chiller. In this case, hot water is stored when available in times with no cooling demand. Storage on the cooling side consists in storing cold water generated by the chiller. In this case, the chiller operates whenever heat is available, even if there is no cooling demand. A way of storing “simultaneously” heating and cooling energy by increasing the storage capacity consists in using Thermo Chemical Storage (TCS) used as air dehumidification process.

The aim of this report is to describe the different possible configurations of TCS in combination with district heating (DH) and decentralised thermally driven cooling processes.

I.2.1 Why using TCS in combination with district heating?

The limitations for using distributed small-sized absorption chillers (AbC) in existing district heating networks were described and assessed in many works, for instance in [Pol, 2008]. In particular, the return temperature increase in the DH network limits the maximal number of chillers which can be connected and operated simultaneously. Problems appear in the time when the heating load for the AbC is high compared to the total load of the other consumer substations. As a result, the necessity to combine AbC with processes with a higher temperature drop on the driving side was shown, as well as the necessity of storage and load management in order to avoid simultaneous operation of many chillers. However, additional storage equipment would lead to additional costs which are not acceptable because of the limited economical feasibility of AbC in combination with DH.

The outcome of [Pol, 2008] was a suggestion to look for other technologies, in particular:

- Systems integrating storage features in their design
- Integration of solar thermal panels (in combination with solar cooling)
- Desiccant and Evaporative Cooling (DEC) systems, which have lower driving temperatures in comparison with AbC and simultaneously have the advantage of allowing for a higher temperature drop on the heating side as for AbC.

DEC systems, if equipped with a sufficiently high amount of sorption material, can be considered as TCS from the perspective of the heat supply technology (DH) they are connected to. On the other side, as they are used for air dehumidification in a sorption cooling system, their use can be assimilated to virtual cooling energy storage. All these advantages have led to the idea to combining TCS with district heating networks.

I.2.2 Target of activities within IEA Task 42

The main target is the simulation based analysis of the technical potential for using small scale sorption storage units in combination with district heating for cooling applications. The following aspects are analysed:

- Impact on the operation of the district heating network
- Load management aspects
  - Which charging and discharging time could be typically foreseen?
  - What would be the required size and capacity of the storage unit to cover cooling loads?
- Energy performance of the entire system (DH and storage unit) in comparison with using decentral AbC

I.3 TCS in combination with DH and thermally driven cooling processes

TCS is based on reversible endothermic and exothermic chemical reactions. One of these reactions is the sorption process. Sorption processes can be categorised into absorption and adsorption, both processes being exothermic reactions. Adsorption is the process occurring when a gas or liquid solute accumulates on the surface of a solid or a liquid (adsorbent), thus forming a film of molecules or atoms (the adsorbate). The physical aspects are different from absorption, in which a substance diffuses into a liquid or solid to form a solution. The term sorption include both processes while desorption is the reverse process which happens with external heat supply (endothermic reaction).

In combination with air-conditioning systems and district heating system (or solar energy), TCS offer a double advantage:

- The endothermic desorption reaction allows for heat storage.
- The sorption material can be used as an air desiccant. The heat stored into the TCS can be released when water is being absorbed or adsorbed into the material in the course of a thermally driven cooling process.

Materials combining TCS with a desiccant cooling process can be categorised into:

- Packet bed or rotary wheel of solid adsorbents (e.g. silica gel, zeolite)
- Liquid desiccant (e.g. lithium chloride)

The use of rotary wheels does not provide any possibility for heat storage, the potential being limited by the rotary speed of wheel. Storage possibilities are given by packed bed.

In parallel TCS can be categorised into:

- Open sorption storage systems: the air to be conditioned is in direct contact with the sorption material. Air dehumidification is done through adsorption of water in the desiccant material.
- Closed sorption storage systems: cooling distribution through a cold water network

For the application of these desiccant materials, the amount of water which can be adsorbed or absorbed is the most important property. Figure 1 shows the maximum water uptake (% in volume) of some commercial available sorbents [Hauer, 2007].

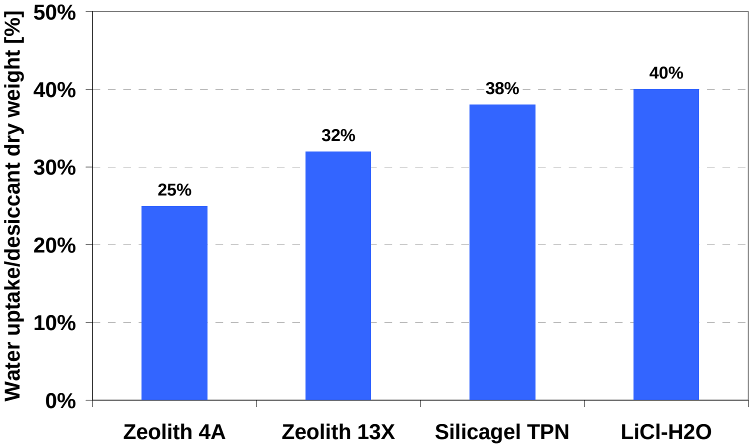


Figure 1: Water uptake of different sorbents, from [Hauer, 2007]

I.3.1 Open sorption storage

Two possibilities for open sorption storage with solid and liquid sorbents are described below.

Figure 3, Figure 4 and Figure 5 show desiccant and evaporative cooling systems (with solid and liquid sorbents) in the charging and discharging phases. The process combines evaporative cooling with a desiccant process (air dehumidification) to increase the cooling potential of evaporative cooling. This combined cooling process is referred to as desiccant and evaporative cooling (DEC).
The discharging phase, shown in
and Figure 4, is done during the day and corresponds to the cooling mode (the energy stored in the TCS in form of sorption energy is delivered to the supply air while the ambient air is being dehumidified).
Figure 3 and Figure 5 show the charging phase of the TCS, done during the night when the TCS is regenerated. The desorption reaction is done under heat supply from external source (e.g. district heating network).

I.3.2 Open sorption storage with solid adsorbent

I.3.2.1 Discharging phase / cooling mode

The discharging phase consists in delivering the heat stored into the TCS.
As shown in
, the ambient air (1) (30°C, 60 % RH) passes the packed bed of Zeolite and exits warmer and drier (2), due to the effect of the sorption reaction. The dry air coming out of the Zeolite packet bed (2) is then being cooled down through indirect and direct evaporative cooling. It passes first through the cold recovery (3) which consists of an indirect evaporative cooler coupled with the exhaust air (5) (24°C, 50 % RH) which is cooled down through evaporative cooling until saturation. The air, still dry (3), is cooled down and humidified (direct evaporative cooling) to reach the required air supply conditions into the building (4).

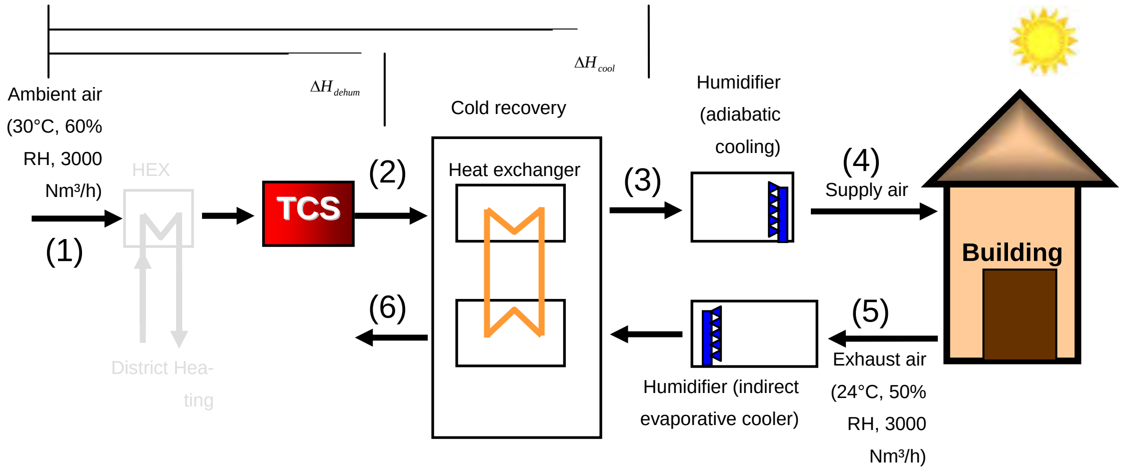


Figure 2: Solid adsorbent storage system: discharging mode

I.3.2.2 Charging phase / regeneration mode

The charging phase of the TCS corresponds to the regeneration of the sorption material. The regeneration of the sorption material consists in removing water from the packed bed. In our case, regeneration of zeolite or silica gel packed bed is done by using warm air heated up by district heating. The warm air enters the TCS to regenerate the sorption material (desorption) and exits in the ambient (3)*. In this way district heating is used during night and heating energy is stored in the TCS.

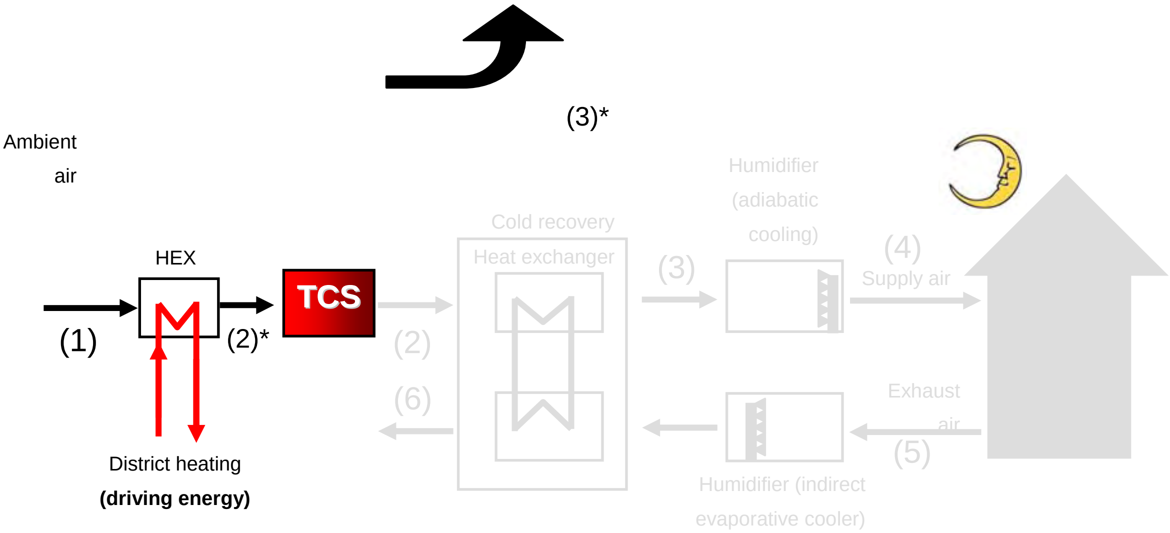


Figure 3: Solid adsorbent storage system: charging mode

I.3.2.3 Demonstration case: jazz club in Munich (Germany)

The most known and well documented demonstration case is the one of a jazz club in Munich. The system design and its performance are reported in [Hauer, 2002], [Paksoy, 2007] and [Hauer, 2007].

The system was installed in Munich in the year 1996 and connected to the local district heating network. Zeolite is used as adsorbent and the system was designed to heat a school in winter and to cool a jazz club in summer time. Both the school building and the jazz club are connected to the district heating network of Munich [Hauer, 2007]. The system is the one described in
and

Figure 3.

Design data are presented in Table 1.

	Parameters
Adsorbent material	Zeolite 13X
Mass of adsorbent	7000 kg
Max air flow	6000 m³/h
Max cooling power	50 kW
Energy density (cooling)	100 kWh/m³

Table 1 – Design data of the demonstration case in Munich, from [Hauer, 2007]

Table 2 shows experimental results of the desiccant cooling system published in [Hauer, 2007]. The highest performance rating (COP) was measured using a desorption temperature of 80 °C.

	Desorption temperature		
	130°C	100°C	80°C
COP_{dehum}	0.45	0.48	0.5
COP_{cool}	0.67	0.8	0.87
ρ_{cool}	168kWh/m³	105kWh/m³	100kWh/m³

Table 2 – Experimental results of the TCS for cooling, from [Hauer, 2007]

The two different coefficients of performance for dehumidification and cooling in Table 2, calculated from monitoring data, are defined as [Hauer, 2007]:

$$COP_{cool} = \frac{Q_{cool}}{Q_{des}} \text{ and } COP_{dehum} = \frac{Q_{dehum}}{Q_{des}}$$

where:

$$Q_{cool} = \int \Delta H_{cool} \cdot \dot{m}_{air} \cdot dt \text{ and } Q_{dehum} = \int \Delta H_{dehum} \cdot \dot{m}_{air} \cdot dt$$

I.3.3 Open sorption storage with liquid absorbent

I.3.3.1 Discharging phase / cooling mode

The general physical principles of TCS with liquid absorbent and solid adsorbent are very similar. As by the solid sorbent, the discharging phase coincides with the physical absorption process.
As shown in Figure 4, the ambient air (30°C, 60 % RH) comes in contact with the concentrated solution of Lithium Chloride, sprayed over an exchange surface, and exits warmer and drier, due to the effect of the sorption reaction. Through this process the ambient air is being dehumidified and the concentrated salt solution diluted. The dry air is then being cooled down through indirect and direct evaporative cooling. It passes first through the cold recovery consisting of an indirect evaporative cooler coupled with the exhaust air (24°C, 50 % RH) which is cooled down through evaporative cooling until saturation. The air, still dry, is cooled down and humidified (direct evaporative cooling) to reach the required supply air conditions into the building.

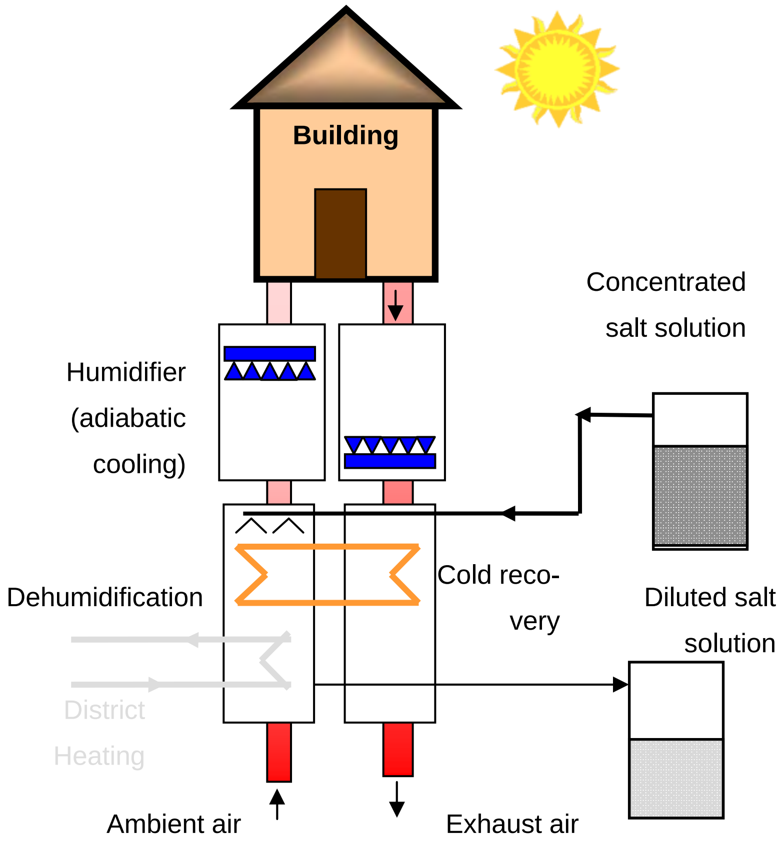


Figure 4: Liquid absorbent storage system: discharging mode

I.3.3.2 Charging phase / regeneration mode

The charging phase corresponds to the regeneration of the sorption material, consisting in increasing concentration of the salt solution by desorption. This process is done by using warm air heated up by district heating. In practice, the diluted salt solution is sprayed over an exchange surface in contact with the inlet air. The inlet air is the ambient air which is warmed up by the district heating.

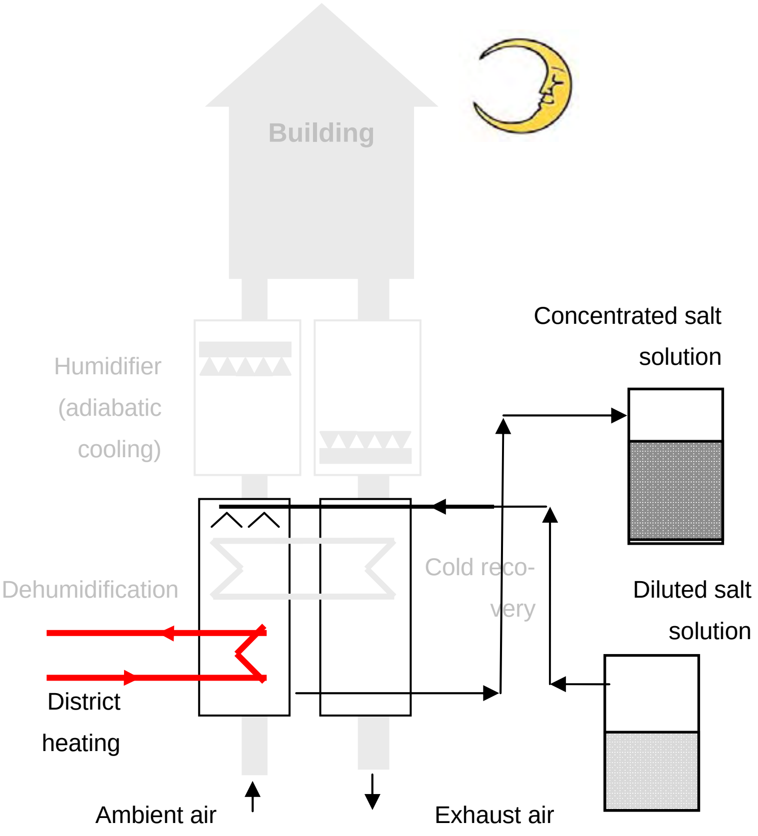


Figure 5: Liquid absorbent storage system: charging mode

I.3.3.3 Demonstration case: office building in Amberg (Germany)

One example of office building using a liquid absorbent in an open cycle for air conditioning is the one of Amberg (Germany). The system design and its performance are reported in [Paksoy, 2007].
The system is installed in an office building and realised as a solar cooling plant. The regeneration of the liquid desiccant is done with solar thermal energy [Paksoy, 2007]. The system is the one described in Figure 4 and Figure 5. Design data are presented in Table 3.

	Parameters
Adsorbent material	Lithium Chloride
Mass of adsorbent	3000 kg
Max air flow	30000 m³/h
Max cooling power	150 kW
Cooling & dehumidification energy per year	20 MWh

Table 3 – Design data of the demonstration case, from [Paksoy, 2007]

The building is in operation since June 2000 and experimental results from that demonstration project were expected in 2005 but still not published at the moment.

I.4 State of the art of computational models of TCS and DH networks

Computational models of TCS and district heating networks have been developed at different scales, depending on the targets followed when analysing the systems (assessment of overall system performance or detailed physical modelling of a component).

I.4.1 Modelling approaches of adsorption and desorption processes

[Wang, 2007] presents a literature review of different modelling approaches for sorption and desorption processes applied on desiccant wheels.
There are also different modelling approaches for desiccant packed beds. Two types of approaches are summarized below:

- Heat and mass transfer models
- Empirical models

I.4.1.1 Heat and mass transfer models

The main modelling steps for a heat and mass transfer model, as described in [Wang, 2000], [Wang, 2007] and [Pahlavanzageh, 2006] are:

i. assumption proposal and selection of an appropriate control volume;
ii. deriving the partial differential governing equations based on the mass and energy balances;
iii. providing auxiliary relation to close the governing equations;
iv. adopting proper mathematical numerical approach to solve the model.

[Wang, 2007] proposes two types of mathematical models:

- Gas-side resistance (GSR) model;
- Gas and solid-side resistance (GSSR) model

It shows that GSSR models are higher in precision and more complex compared with GSR models.
The physical modelling approach is too detailed for the project needs, as the analysis is done at a system level (district heating). Thermodynamic equations are needed in order to describe the current state of the TCS unit in function of defined input data (inlet air temperature and its relative humidity). These curves can be determined in an empirical way.

I.4.1.2 Empirical models

Two simple mathematical models, from [Beccali, 2003] and [Beccali, 2004], based on experimental data are proposed to evaluate the performance of rotary desiccant wheels using different types of solid desiccants (silica gel, LiCl, etc). These models are derived from the interpolation of experimental data obtained from the industry and the correlations have been developed for predicting outlet temperature and absolute humidity. The so-called ‘Model 54’ consists of 54 coefficients corresponding to each correlation for outlet absolute humidity and temperature. It is shown that the model predicts very well the performance of silica gel desiccant rotors (type I). The other model (Model 4, a psychrometric model) gives relatively simpler correlations for outlet temperature and absolute humidity. The developed psychrometric model is based on the correlations between the relative humidity and enthalpy of supply and regeneration air streams. It can be used to predict the performance of three types of desiccant rotors (Types I, II and III) manufactured by using different kind of solid desiccants. The model has been tested and validated with a wide range of measurement data obtained from the industry.

The approach used in the following is similar to the one proposed by [Beccali, 2003] and consists in using empirical models (generating characteristic curves) documented in literature ([Diran, 1997], [Hauer, 2007]). Simplified models described by approximated function are used to calculate outlet temperature and humidity after the adsorption process. The choice of simplified models lies on the aim of the project which is to evaluate the influence of a desiccant cooling system (used as a storage in desorption) in a DH network regardless the details of the thermo dynamical process in the silica gel.

I.4.1.3 Description of chose model

The silica gel fixed bed is modelled by using characteristic curves taken from literature [Diran, 1997]. As described above, simplified models described by approximated function computing outlet temperature and humidity are used since the scope of the project is to evaluate the influence of the storage in a DH network and not to simulate in detail the thermo dynamical process in the silica gel. The basics of the silica gel bed model are taken from [Diran, 1997]. The outlet temperature, during the adsorption process, is obtained by calculating the temperature increase as proposed by [Diran, 1997]

$$\Delta T = Y_F \Delta H / C_{pb} \qquad \textit{Equation 1}$$

Y_F	humidity inlet
ΔH	heat of adsorption
C_{pb}	heat capacity of air

The outlet absolute humidity is calculated by considering a fixed desiccant bed which would be large enough to remain non-saturated during the entire adsorption process. This assumption means that there is always enough dry sorption material and the outlet absolute humidity can be lowered to 0.006 kg/kg regardless the inlet conditions, which of course represents very ideal conditions.

Figure 6 shows how much water can be absorbed in 1 kg of dry material at a given relative humidity. Total amount of material needed is calculated by linearising of the moisture isotherm curve for silica gel provided by [Diran, 1997] (see Figure 6).

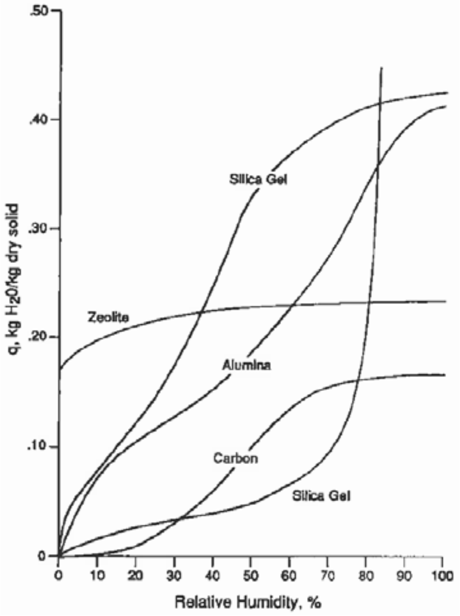


Figure 6: Moisture isotherms from [Diran, 1997]

I.4.2 Modelling approaches of district heating network

Modeling the dynamic behavior of a district heating network requires modeling both hydraulic and thermodynamic aspects of the system (pressure distribution, pump requirements, heat losses, temperature distribution in the network, etc.). Mathematical models involve a full physical modeling of the network, taking into account the network topology, individual pipe properties, material properties, pumps, etc. In this framework DH simulation software enables a comprehensive overview of the network helping the initial design and subsequent modifications of the network.

Different tools are available, for modeling and simulating the performance of DH networks (commercial, freeware or self-developed) and a list of them is reported below:

- SisHyd [Bentley, 2010]
- Sir3S [3sconsult, 2010]
- Apros [Apros, 2010]
- Stanet [Stafu, 2010]
- Dymola [Dymola, 2009] [Modelica, 2010] (using the Modelica Fluid Library)
- T*SOL Professional [Valentin, 2010] (simulation and design of local district heating systems)
- EC.GIS [Globema, 2010] (district heating network inventory and management)

Most of the simulation tools listed above (SisHyd, Sir3S, Apros, EC. GIS) provide a Geographical Information System (GIS) interface, which make them easy to use for modelling systematically large DH networks.

A rough analysis of these existing commercial tools, pointed out advantages in simulating complex DH networks with Modelica/Dymola for research purposes. These can be summarized as following:

- Bi-directional fluid flow, necessary to model intermeshed networks
- Possibilities to combine buildings' models developed in the same modeling environment
- Possibilities to integrate models of other engineering fields (material properties, thermo-mechanical stresses…)
- Possibility to consider instationary effects and dynamic hydraulic phenomena
- Possibility to implement customised control strategies

In particular, the models of the storage (silica gel bed), of the desiccant cooling system and of the district heating network, computing the dynamic or steady-state response, are all developed in Modelica on the basis of the Modelica Fluid library [Modelica].

Modelica is an open source modeling language, consisting of a language standard definition along with a large collection of basic model components from various fields, the so-called Modelica Standard Library. The Modelica language is built around two basic concepts of algebraic and acausal modelling. This allows the user specifying the models by using algebraic equations, which can be derived from the basic physical properties, and enter them directly into the simulation environment without needing to adapt to the solving algorithms implemented in the software. Furthermore, all models are a priori acausal, and allow for considering phenomena like changing flow directions without having to specify them explicitly in the model. The Modelica language is implemented in several tools, from which Dymola is chosen for the implementation.

Following physical phenomena are considered in the Dymola model of the DH network:

1. Temperature drop and heat losses
2. Pressure drop
3. Heat capacity

I.5 Simulation

The limitations for using distributed small-sized absorption chillers in existing district heating networks, described in part I.2.1, are the starting point for the project. A desiccant cooling system (open sorption storage with solid adsorbent), as shown in I.3.2, is chosen and the overall system performance is assessed by using the simulation model, considering a time interval of one week. A comparison by using AbC in combination with DH network is done.

I.5.1 Simulation procedure and work flow

The general procedure for the simulation used to assess the possibility of using sorption storage in combination with a DH network is summarized in Figure 7. As a first step, a simulation of an open sorption storage unit is conducted and partly validated by using monitoring data. The system proposed, as shown in I.3.2, is based on the same principles of a desiccant cooling system (DEC) where the rotary wheel is replaced by a large fixed bed (storage). The choice of a daily storage capacity is needed, since the target is to shift heating loads (used in the desorption mode) from day to night.

As shown in Figure 7, following input data, are gathered for the network simulation:

- Heating loads from [Pol et al., 2008]
- Assumed cooling load profiles for a typical office building

Cooling loads for a typical office building in a single day are considered similar for the week of interest and are used as input for the storage simulation (adsorption) to calculate the heating loads in the desorption phase and the total mass of sorption material (simulation of the cooling phase and of the storage phase are performed in two different steps).
Total heating loads for domestic hot water preparation at other consumers connected to the network and for desorption of the silica gel bed are evaluated and an iterative approach is used in order to determine in first approximation the size of the network piping (consecutive simulations are performed to obtain the optimum network sizing).
Finally the evaluation of the network performance is done to assess the different proposed scenarios. The indicators chosen for assessing network and storage performance are described in sections I.5.3.1 and I.5.4.

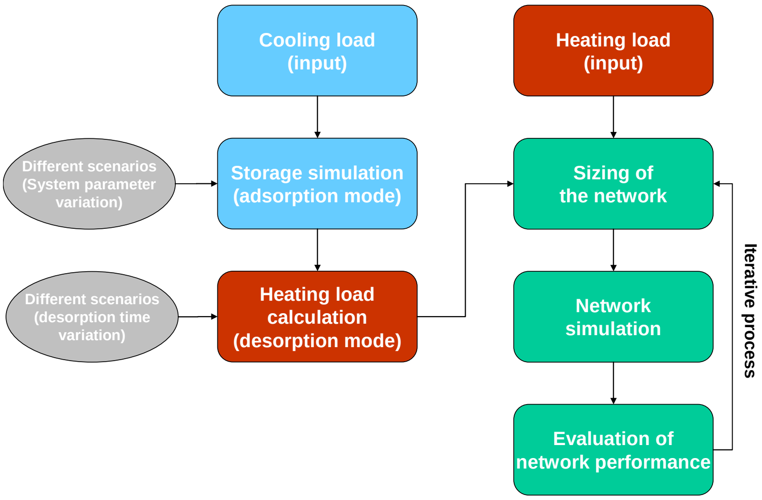


Figure 7: Workflow description

I.5.2 Description of the system modelled

I.5.2.1 DH network: model and parameters

A theoretical district heating network is used for the assessment. In the next project phase a real system will be analysed in order to evaluate the influence of the storage position in the network as well.
The system consists of a centralized generation of hot water at a temperature level of 90°C and given maximal mass flow rate, distributed through the district heating network to the consumer substations. The length of supply line of the network is 375 m, as shown in Figure 8. Different load profiles are taken from a real network (data from [Pol et al., 2008]) in order to model a realistic behaviour of the DH network.
The DEC system (TCS) is considered as a consumer connected to the network. The load profile, defined by a temperature drop and a mass flow rate of the heating coils heating up the air stream for regeneration, is calculated from the storage simulation in specific conditions (see Figure 15). In this case the heat exchanger used for heating up the air stream in the regeneration process is not considered and a sensitivity analysis, considering different levels of temperature drops in the water side, is performed by varying the temperature drop in the range between 30°C and 45°C, corresponding to observed levels of temperature drop in reality (monitoring data from a solar cooling system).
A second sensitivity analysis is done by varying the size of the storage unit, by changing the mass flow rate of the substation (with a fixed regeneration time). The size of the cooling system is modified between 12 kW and 48 kW, which consequently has an impact on the size of the fixed bed to be used in order to be capable to adsorb humidity in the cooling mode. The time interval of usage of the cooling system is chosen as the time between 8:00 and 17:00.
Silica gel is used as sorption material due to its lower temperature requirements for the desorption, which makes the silica gel more suitable for application in connection with a district heating network with a supply temperature of 90°C. In the defined control strategy the heating is provided to the bed through a heating coil during the night from 22.00 with a time of desorption of 2.5 h, 5 h and 10 h.

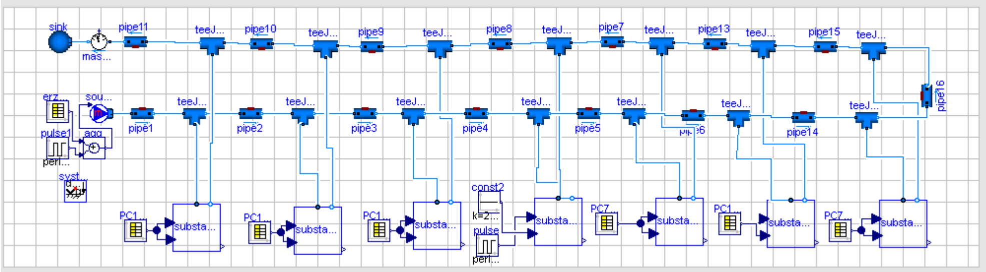


Figure 8: District heating network model configuration in Dymola

In the DH simulation as well as in the cooling system simulation electricity consumption for the pump and the ventilator is not considered.

I.5.2.2 Load profile: heating and cooling load

Heating load profiles for space heating and domestic hot water are taken from the monitoring data of the network in Mureck, Austria. The different load profiles are defined by calculating from the metered temperature drop and mass flow rate of the primary side of the substations, shown from Figure 9 to Figure 12.

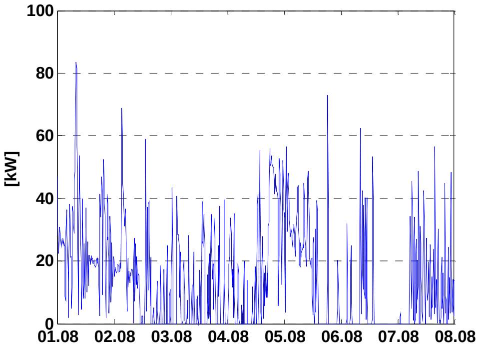


Figure 9: Heating load profile, Storage room

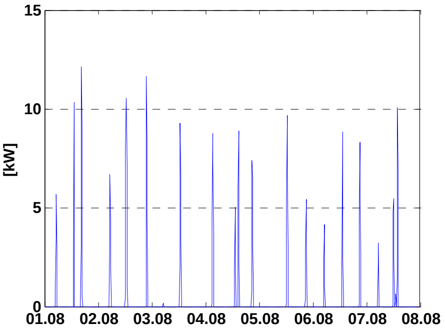


Figure 10: Heating load profile, Single family house 1

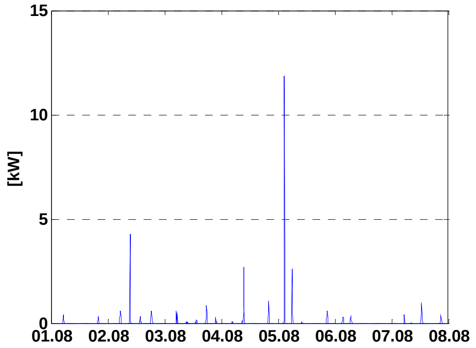


Figure 11: Heating load profile, Single family house 2

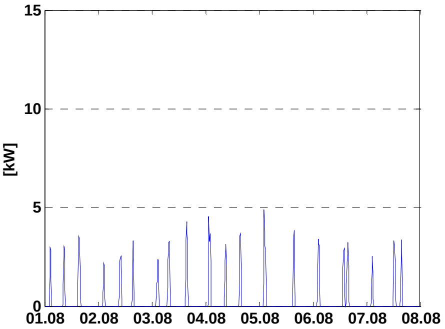


Figure 12: Heating load profile, Single family house 3

The heating load profiles from Figure 9 to Figure 12 are related to three different single-family house consumers and a large industrial consumer (storage facilities). They don't depend on weather parameters (outside air temperature or solar radiation). The installed heating capacity of each of the four substations is listed in the Table 4.

	Installed heating capacity of substation [kW]
2 x Household type 1	15
1 x Household type 2	29
2 x Household type 3	6
1 x Storage room	127
1 x TCS	12-48

Table 4 – Installed heating capacities of substations

The total installed capacity in the networks amounts 200 kW, without considering the TCS. A coefficient of simultaneity of s=0.45 is calculated in the considered week, defined as:

$$s = \frac{Q_{Max,Op}}{Q_{Installed}}$$

Equation 2

$Q_{Max,Op}$	Maximum heating load in operation in the time-interval [kW]
$Q_{Installed}$	Installed heating load capacity [kW]

The cooling loads used for the simulation of the desiccant cooling system and the calculation of the heating loads corresponding to the charging phase of the storage are calculated from monitored weather data (weather station in Seibersdorf (Austria), [ZAMG, 2009]) for the year 2009 and typical fresh air requirements for an office building. Outdoor temperature and absolute humidity for the first day of August 2009 is taken into account and used for the simulation of the desiccant cooling system as shown on Figure 13. The average outdoor temperature is about 23°C and a peak of 31°C occurs between 13:00 and 15:00. The average absolute humidity is ca. 0.011 kg/kg and reaches a peak of about 0.013 kg/kg.

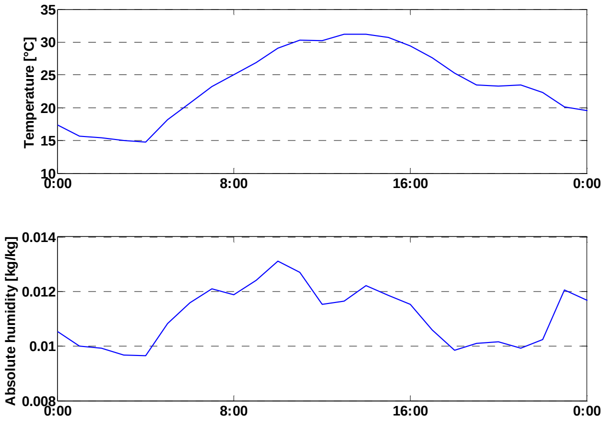


Figure 13: Outside temperature and absolute humidity of air (01.08.09)

Cooling load calculation is performed for a day of reference and then used for the entire week of interest in the network simulation, as described in Figure 14.
Assumptions considered to derive the supply mass flow rate to the room are:

Building type	private office
Useful floor area	120 m²
Air change rate	4 1/h

Table 5 – Assumptions for the cooling load calculation

I.5.3 DEC system simulation

The simulation of the DEC system provided the total amount of energy for desorption and the mass of silica gel needed for the fixed bed, which represents the starting point for the simulation of the storage. Considering the energy for desorption needed, the heating loads are calculated and used for the network simulation. Figure 14 shows in detail the process used to calculate the heating loads used for the network simulation starting from the cooling loads.

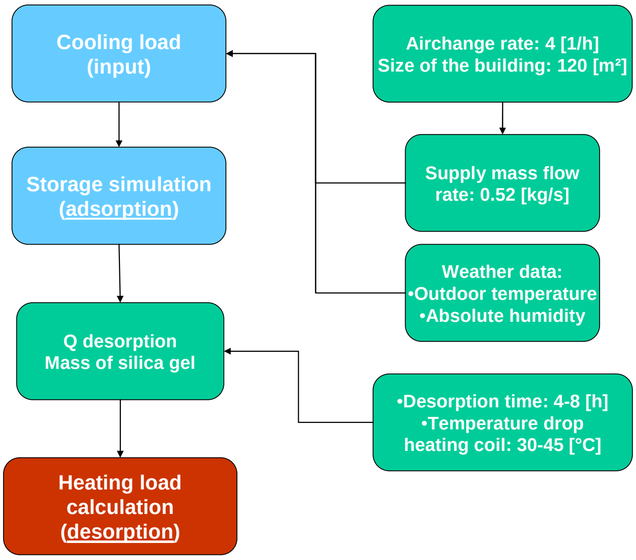


Figure 14: Workflow description, adsorption and desorption mode

Cooling (total and sensible) and heating energy (in desorption phase) are calculated as following by using Equation 3 to Equation 5:

$$Q_{cooling} = \int \dot{m}_{flow} \Delta H_{outdoor-supply} dt \qquad \text{Equation 3}$$

$$Q_{sensible} = \int \dot{m}_{flow} cp_{air} \Delta T_{outdoor-supply} dt \qquad \text{Equation 4}$$

$$Q_{heating} = Q_{des} = \int \dot{m}_{flow} \Delta H_{SilGel\_bed} dt \qquad \text{Equation 5}$$

Referring to the outside air temperature and absolute air humidity, according to Equation 3 to Equation 5, Figure 15 shows the cooling load profile used to calculate the heating load in the network during the charging phase (night).
Simulation of the DEC system in cooling mode shows the total and sensible cooling loads as well as the assumed schedule of the air mass flow rate into the office.

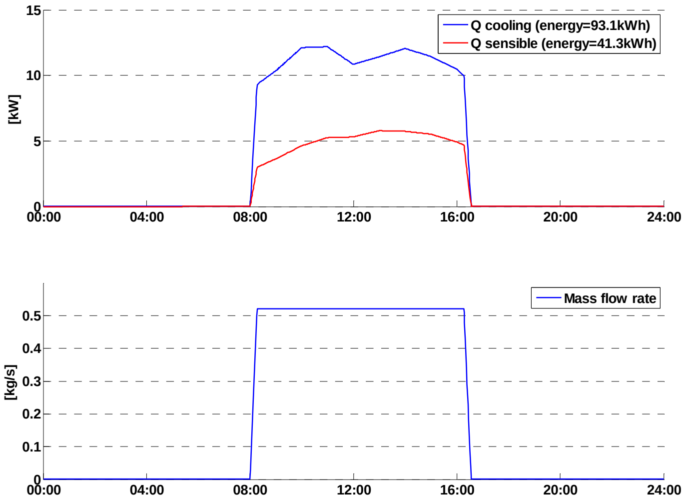


Figure 15: Reference cooling load profile and assumed mass flow rate for the ventilation system

A total cooling load about 12 kW (ca. 8 kW for latent heat removal) is calculated.

I.5.3.1 Desiccant cooling system (adsorption mode)

The desiccant cooling system model in the Dymola model, previously described in **Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 3, is shown in Figure 16.

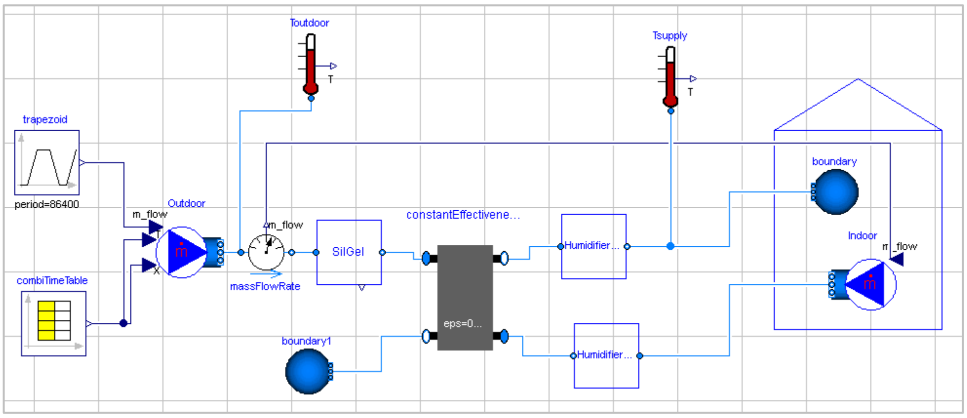


Figure 16: Desiccant cooling system model in Dymola

The heat exchanger model, considering a constant effectiveness and the humidifier model is taken from the LBL building library 0.8.0 [Wetter, 2009].
For the cold recovery and the control of the humidification process no specific data were available. In this sense sensitivity analysis, by considering a range of constant effectiveness for the heat exchanger and different control strategy for the humidification of the supply air, is done. The assumptions considered are summarized in Table 6.

Description	Range
HeX effectiveness	0.75 – 0.9
Supply %RH	35 - 50

Table 6 – Sensitivity analysis: HeX effectiveness and supply % RH

Performance of the cooling system is assessed with two different indicators, COP_{cool} and the maximum cooling load provided $Q_{cool\ peak}$.

Referring to outdoor conditions specified in Figure 13, the simulation results of the reference day in August for the different cases are summarized in Table 7. Figure 18 shows the performance of the system in the design condition (constant effectiveness of 0.85 and 50 % RH).

	COP_{cool} **[-]**	$Q_{cool\ peak}$ **[kW]**	**Supply air temperature [°C]**
HeX effectiveness (50 %RH)			
0.75	0.617	9.7	22.1
0.8	0.692	10.9	21.2
0.85	0.766	12.0	20.2
0.9	0.841	13.1	19.3
Supply %RH (HeX, 0.85)			
35	0.772	12.1	23.1
40	0.770	12.0	22.1
45	0.768	12.0	21.1
50	**0.766**	**12.0**	**20.2**

Table 7 –COP cooling, $Q_{cool\ peak}$ and supply air temperature for the different scenarios

The effect of changing the heat exchanger effectiveness can be quantified from the results in Table 7. By increasing the heat exchanger effectiveness, COP_{cool} of the system increases and the supply air to the room decreases (for a larger effect of the cold recovery). Changing the supply air humidification control strategy has an irrelevant effect on COP_{cool} but this helps to decrease the supply air into the room (due to the humidification cooling effect).

Limitations on the system design are set with respect to the supply temperature. In order to guarantee a supply air temperature in the range 20°C -22°C (with a relative humidity ratio of 50 %) a value for the heat exchanger effectiveness at least 0.8 is necessary.
The system design derived from Table 7 considers a heat exchanger effectiveness of 0.85 and a supply air humidification at 50% RH. The choice is done by considering a compromise between an affordable solution for the HX (0.9 represents a very high value for HX effectiveness) and a high value of the COP_{cool} .

Evaluation of the thermodynamical cycle in the h-x diagram is reported in Figure 17 (blue line) and Table 8.

Description	Temp.	Relative Humidity	Absolute Humidity	x from R.H.	R.H. from x
	°C	%	g/kg	g/kg	%
Outdoor air	30,0	50,0		13,3	50,0
after Sorption	60,0		6,0	6,0	4,8
after Cold recovery	26,0		6,0	6,0	28,7
after Humidification	20,0		7,5	7,5	51,5

Table 8 – System design conditions

The ambient air at 30 °C and 50 % RH passes the packed bed of silica gel and exits warmer (due to the sorption reaction) at a temperature of 60 °C and drier at a relative humidity ratio of 5 % RH. The dry air coming out of the silica gel packet bed is then cooled down at constant absolute humidity through the cold recovery, leaving at 26 °C. Last, the expected air supply conditions into the building (20 °C and 50 % RH) are obtained by evaporative cooling.

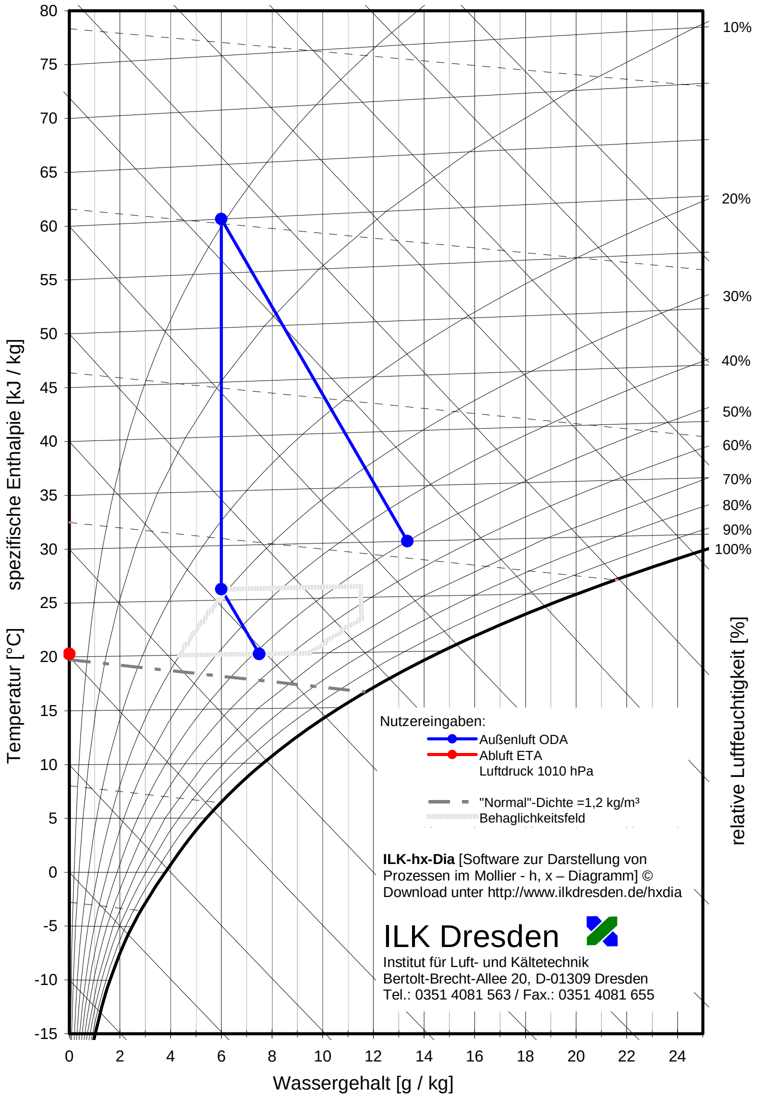


Figure 17: Desiccant cooling system process in the h-x diagram

I.5.3.2 Desiccant cooling system (desorption mode)

The total amount of heating energy to be provided during the charging phase for desorption of the fixed bed of silica gel (Figure 18) is calculated as an output of the storage model simulation (in adsorption mode), with a value of 119.6 kWh/day (for the cooling system size of 12 kW).

Assuming that the moisture isotherm of Figure 6 is valid for this application, the total amount of silica gel required is 360 kg. Considering a packed bed density in the range of 450-700 kg/m³ [Hauer, 2007], the minimum amount of volume required is 0.10-0.16 $m^3/kW_{peak\_installed}$. In the considered system design conditions it corresponds to a required volume of 1.2-2 m³.

In the network simulation starting from the total amount of heating energy a sensitivity analysis with different desorption time scenarios is made, I.5.4.

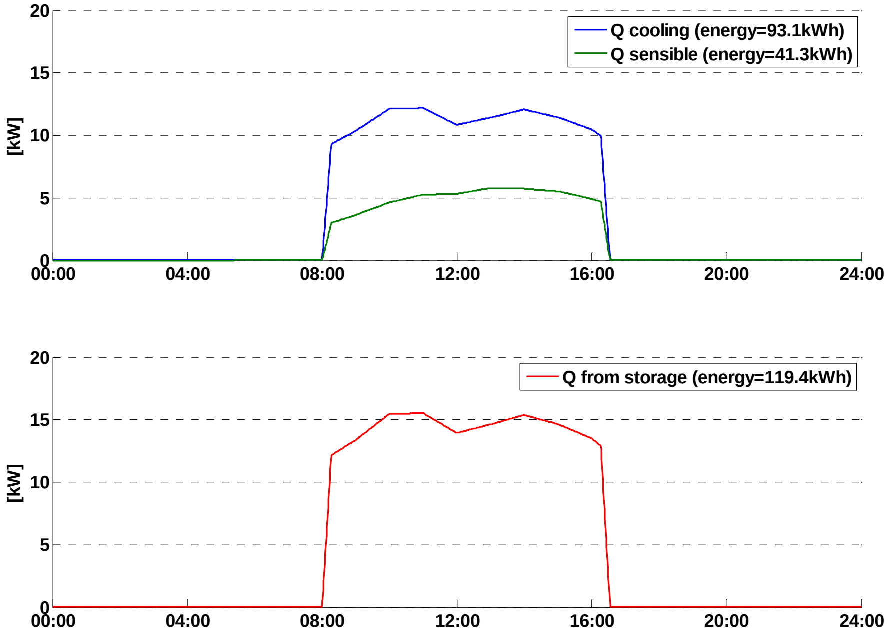


Figure 18: Total and sensible cooling energy, adsorption mode (top); Energy from the storage (bottom) to be provided in desorption mode.

I.5.4 Network simulation and system performance evaluation

The network design is based on the maximally accepted fluid velocity in the piping and heat losses minimization in the network. From the simulation results a value of DN50 is chosen, [KELIT, 2006].

Eleven different scenarios are considered for the assessment of the system. The following aspects are considered in parameter variation::

- size of the storage between 12 kW and 48 kW
- temperature drop of the heating coil between 30 °C and 45 °C
- desorption time of 2.5 h, 5 h and 10 h

The different scenarios are summarized in Table 9.

	Cooling load [kW]	Temperature drop [°C]	Desorption time [h]
Scenario 1a	12	30	8
Scenario 2a	24		
Scenario 3a	36		
Scenario 4a	48		
Scenario 1b	12	30	8
Scenario 2b		35	
Scenario 3b		40	
Scenario 4b		45	
Scenario 1c	12	40	10
Scenario 2c			5
Scenario 3c			2.5

Table 9 – Definition of the different scenarios

For the evaluation of the district heating network performance three different aspects, by defining three appropriate different indicators, are considered:

1. Total heat losses in the network, $Q_{losses} = \frac{Q_{consumed}}{Q_{produced}}$
2. maximum return temperature $T_{\max\_ret}$ (corresponding to the minimum

temperature drop compared to the supply line) in the operating time-interval

3. average temperature drop $\overline{T}_{drop}$ of the network (average difference between the supply and the return line)

Evaluation of the influence of the storage on the network performance is presented in Table 10 and in Figure 19 as well as the influence of using an AbC (of the same cooling capacity) in combination with a DH network.

	Q_{losses} **[%]**	$T_{\max\_ret}$ **[°C]**	$\overline{T}_{drop}$ **[°C]**
Reference (without storage)	19,7	84,0	25,0
Reference (with absorption chiller)	16,0	84,0	19,8
Scenario 1a	17,7	82,7	25,9
Scenario 2a	16,6	82,7	26,5
Scenario 2a	15,8	82,7	26,9
Scenario 3a	15,2	82,6	27,1
Scenario 1b	18,7	82,7	24,6
Scenario 2b	18,2	82,7	25,3
Scenario 3b	17,7	82,7	26,0
Scenario 4b	17,3	82,6	26,3
Scenario 1c	17,7	82,6	25,9
Scenario 2c	18,7	83,6	26,0
Scenario 3c	18,6	84,0	25,7

Table 10 – Performance indicators for three different scenarios

In case of using an AbC in combination with a DH network the main effect is an increase of the return line temperature, caused by the small temperature drop on the generator side, which limits the number of AbC in the DH network,.

For all scenarios a value of Q_{losses} above 15% is calculated due to few consumers installed in the network. Using sorption storage units network usage increases, thus leading a lower share of distribution losses. Total losses decrease (in the best case of scenario 4a corresponding to the highest cooling capacity of 48 kW by about 5%, from 20% down to 15%). Temperature drop variation of the heating coils has less influence on the losses reduction, which for a temperature drop in the heating coil of 45°C is about 17.3% of the total energy produced. Desorption time has a small influence on the heat losses of the network, causing a maximum reduction of 2%.

The maximum return temperature is not influenced by the amount of energy required in the charging process. Increasing the cooling capacity both by reducing the desorption time and by increasing the mass flow rate through the storage tank leads to a decrease in the range of 1-2°C of the maximum return temperature. A reduction of maximum return temperature is predictable, since the charging process is scheduled in the time interval where the total heat consumption is low (and the temperature drop due of the other consumers is also very low compared to the one caused by the storage charging process). To increase the effectiveness further improvements in the control strategy should be analysed. Increasing the temperature drop of the heating coils leads to reduction of maximum return temperature about 1-2°C. Reduction of the desorption time decreases possibilities to benefit from a reduction of the maximum return temperature, since the beneficial effect of a large temperature drop caused by charging the storage is related to smaller time interval.

The average temperature drop between the supply and return line is another important performance indicator of a DH used as source for running a cooling system. As explained in I.2.1 usage of absorption chillers in combination with DH networks is limited because of their low temperature drop on the generator side. By using the proposed desiccant cooling system, substantial benefits can be achieved. The most influencing parameters, from the analysis of the results, are represented by the temperature drop of the heating coil and the cooling system size. Increasing the temperature drop caused by the storage beyond the temperature drop of other traditional consumers has as main effect on the average temperature drop increase, which could be increased of about 1.5°C. Varying the cooling system size at constant temperature drop, can increase the temperature drop of about 2.0 °C. Desorption time has less influences with a maximum increase of 1.0°C.

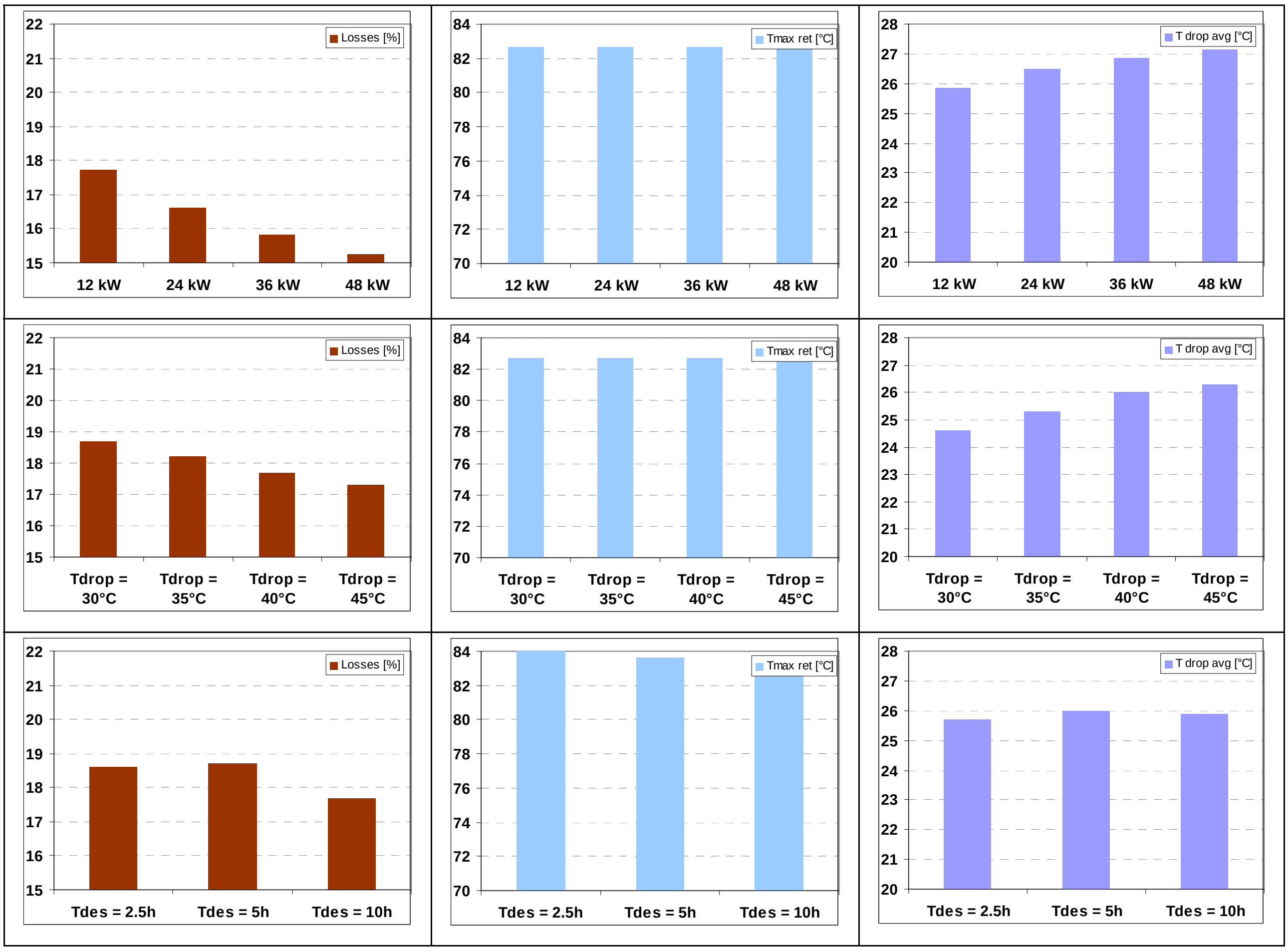


Figure 19: Scenario comparison: influence of cooling system size, temperature drop of the heating coil and desorption time

The analysis of the results shows that particular importance has to be considered in the design of a DEC cooling system in combination with a DH on the heating coil temperature drop, which has the main influence on the return line. In the case of a 12 kW cooling power, with 40°C temperature drop at the heating coils and a desorption time of 10 h, the return temperature and temperature drop with/without the sorption storage and by using an AbC (12 kW thermal cooling power) are shown in Figure 20. Compared to the AbC which decreases of 5°C the average temperature drop between supply and return line, the introduction of a TCS is capable of increasing an average value of 2°C, being thus more interesting for DH network operation than absorption chillers. Temperature drop are drastically reduced by operating an AbC (in the all range of temperature drop, see Figure 20) instead using a DEC system can increase it in the range of 0°C-40°C.

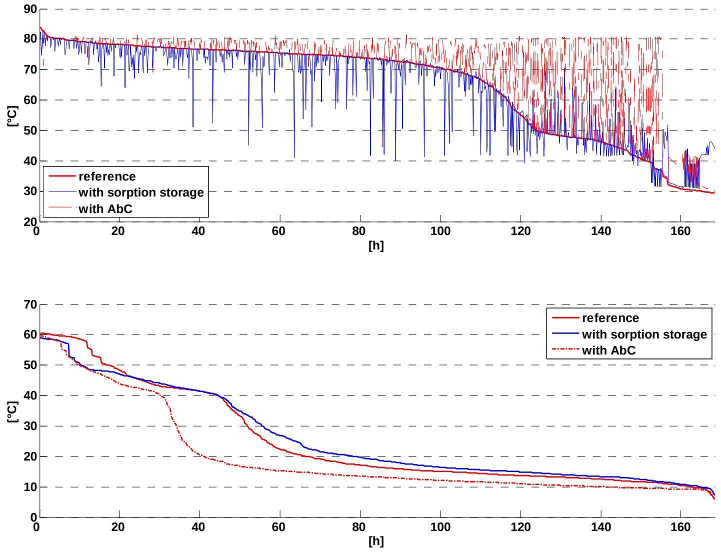


Figure 20: Return line (top) temperature with/without storage and with an AbC sorted descending according to the reference scenario; temperature drop (bottom) in cases with/without storage and with an absorption chiller sorted descending

In terms of heating consumptions, increased energy usage is due to the operation of an AbC or a DEC system, Figure 21. This increase in the energy usage determines consequently lower energy losses in the DH network.

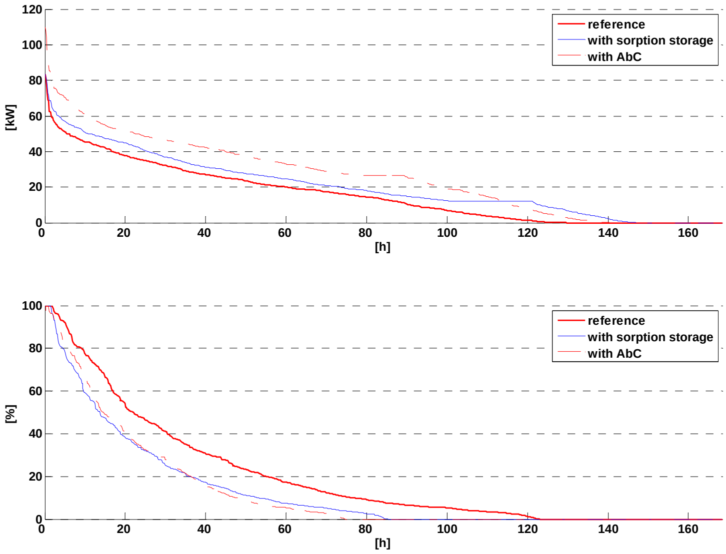


Figure 21: Energy consumed (top) with/without storage and with an AbC; distribution losses (bottom) with/without storage and with an AbC

I.5.5 Evaluation and comparison of the primary energy of the cooling system

The evaluation of the system design from a primary energy point of view is based on primary energy factors (PEF) calculated using GEMIS 4.5 or taken from literature. A list of PEF used in reported in Table 11.

Quantity	Value	Source
Electricity (Scenario EU)	3,14	[EN15603:2008]
Gas	1,36	[EN15603:2008]
Geothermal energy	0,067	Gemis calculation
Solar thermal system	0,28	[Frischknecht, 2008]

Table 11: Primary energy factors

The PEF for geothermal energy is calculated on the basis of assumptions listed in Table 12. The PEF for solar thermal is taken from [Frischknecht, 2008] (one-family house for production of hot-water)

Description	Assumption
Software	Gemis 4.5
Name of process	Geothermie-MW-DE
Time reference	2000
Data input through	Uwe R. Fritsche – Öko Institut (Germany)
Data quality	Estimation (no reference)
Comments	Geothermal heat plant, including well development (steam-dominated well, less than 1 000m deep), no direct emissions

Table 12: Calculation assumptions for the calculation of the PEF for geothermal energy in the software Gemis 4.5

Primary energy and final energy are shown in Figure 19 for the different scenarios. In the analysis a traditional air conditioner (COP=3) is compared with the desiccant cooling in combination with a DH network, which has as source:

- Gas
- Geothermal
- Solar thermal system
- 50% geothermal and 50% solar thermal system

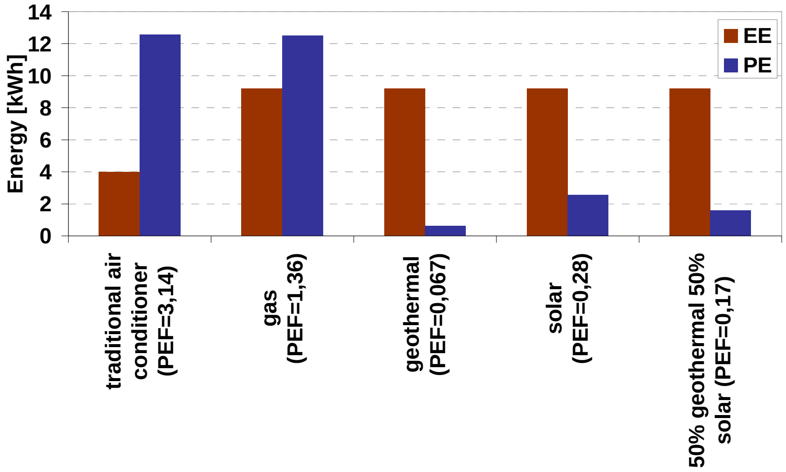


Figure 22: Comparison in terms of final energy and primary energy

Result of the analysis is that the greatest reduction, in terms of primary energy, can be obtained by using a district heating network with geothermal as heat source, with a theoretical value about 90%.

I.6 Conclusions and outlook

The aim of the simulation-based analysis was to define conditions whether or not a DEC system with TCS storage can have technical potentials in combination with district heating for cooling applications. The motivation for this analysis comes from the limited possibilities for using AbC in district heating (DH) networks because of a two high increase of return temperature in the DH network, thus limiting the number of AbC which can be operated simultaneously.

An overview of existing applications of this technology was first carried out. A literature review regarding the state of the art of computational models for TCS and DH network was accomplished. Silica gel fixed bed model was developed in the simulation tool Dymola and the implementation of the storage model in a DEC cooling system was done in order to evaluate the effect of integrating the storage unit into DH network. The model of the DH network was implemented in the environment Dymola. The main conclusions of the feasibility study can be summarised as:

- The share of distribution losses in the DH network can be reduced, resulting from an increased use of the DH network (same advantages by using absorption chillers)
- DEC systems, using heating coils with high temperature drop, may help to decrease the maximum return temperature in comparison to absorption chiller (in which the temperature drops are limited to low values).
- There are no limitations in terms of cooling power installed, since the return line temperature benefit from the TCS charging phase (the average return temperature can be reduced up to 2°C in the cases considered). This is the main advantage compared to using AbC.
- A reduction of nearly 90% of primary energy use can be achieved, compared to a traditional air conditioner (in case the DH network uses geothermal energy as source).

Some aspects, which were not analysed in the project, will be explored in the future work. Target of the future study will be:

- Implementation of a more complex system for a sensibility analysis with respect to the storage position in the DH network (a small influence on the performance of the DH network is expected)
- Definition of different control strategies, in order to determine an optimum for:
  - Increasing the average temperature drop
  - Decreasing the maximum return line temperature
- Implementation of liquid systems, with referring to the system described in I.3.3., to explore eventually advantages compared with solid systems
- Evaluation of the system in different climates

I.7 References, list of figures and tables

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