An Update on Activity C1 Design Tools and Models, Task 65 Solar Cooling Sunbelt Regions

Lu Aye[1*], Nayrana Daborer-Prado[2], Daniel Neyer[3,4], and Uli Jakob[5]

[1]Renewable Energy and Energy Efficiency Group, Department of Infrastructure Engineering, Faculty of Engineering and Information Technology, The University of Melbourne, Victoria 3010, Australia

[2]University of Applied Sciences Upper Austria Campus, Energy Research Group ASIC, Stelzhamerstraße 23, 4600 Wels, Austria

[3]Neyer Brainworks GmbH, Oberradin 50, 6700 Bludenz, Austria

[4]University of Innsbruck, Innrain 52, 6020 Innsbruck, Austria

[5]dr. Jakob energy research GmbH & Co. KG, Pestalozzistraße 3, 71384 Weinstadt, Germany

Abstract
This brief extended abstract reports about IEA Solar Heating and Cooling (SHC) Task 65 and Australia's engagement within the task. Australia has been contributing to Subtask C: Assessment and Tools. The initial findings from the literature on solar cooling system design tools and models are also presented.

Keywords: IEA; Sunbelt region; solar cooling; assessment; design tool

Introduction
IEA SHC is the world's largest Solar Heating and Cooling research network established in 1977 and it promotes the use of all aspects of solar thermal energy (IEA SHC, 2021). The work is accomplished through the international collaborative effort of experts from member countries and the European Union. Australia is one of the member countries since 1979. There are several projects (Tasks) which study various aspects of solar heating and cooling. One of the projects, Task 65 focuses on innovations for affordable, safe and reliable solar cooling systems. The following section describes about Task 65 and its Subtasks.

IEA SHC Task 65 Solar Cooling Sunbelt Region
The IEA SHC Task 65 is built on the following completed tasks (Neyer & Jakob, 2020):

- Task 25: Solar Assisted Air Conditioning of Buildings (June 1999 – May 2004) https://task25.iea-shc.org/,
- Task 38: Solar Air-Conditioning and Refrigeration (September 2006 – December 2010) https://task38.iea-shc.org/,
- Task 48: Quality Assurance & Support Measures for Solar Cooling Systems (October 2011 – March 2015) https://task48.iea-shc.org/, and
- Task 53: New Generation Solar Cooling & Heating Systems (PV or solar thermally driven systems) (March 2014 – June 2018) https://task53.iea-shc.org/.

The main aim of the global IEA Solar Heating and Cooling research platform Task 65: Solar Cooling for the Sunbelt Regions (July 2020 – June 2024) is development of innovations for affordable, safe and reliable cooling systems for sunbelt regions worldwide (Jakob, 2020). The strategy is a combination of cost reduction, simplifications of the systems and stimulation of market conditions through policies. Task 65 covers the small to large size segment of cooling and air conditioning (2 kW – 5 MW). Solar thermal and solar PV technology path ways are considered to be integrated within the HVAC system. Task 65 is organised in four main activities/subtasks (Table 1).

Table 1. IEA SHC Task 65 subtasks and their activities

Subtask	Activities
A: Adaptation	A1 Climatic conditions & applications A2 Adapted components A3 Adapted systems A4 Building and process optimization potential A5 Standardization activities
B: Demonstration	B1 Show cases on system and component level B2 Design Guidelines B3 KPI definitions B4 Standardized Solar Cooling Kits B5 Lessons learned (technical and non-technical)
C: Assessment & Tools	*C1 Design tools and models* C2 Database for technical and economic assessment C3 Assessment mechanism C4 Benchmarking and sensitivity analysis
D: Dissemination	D1 Homepage/publications D2 Policy advice & financing models D3 Guideline/Roadmaps for sunbelt countries D4 Book or booklet D5 Workshops D6 Stakeholder Engagement

Australia signed the participation commitment letter for IEA SHC Task 65 on 4 December 2020. The University of Melbourne has been contributing to Subtask C. The first two authors of this articles co-lead Activity C1 Design tools and models of Subtask C. The following section describes the objectives of Activity C1 and presents the initial findings from the literature.

Activity C1 Design tools and models

The pathways to achieve the main aim of Task 65 are adaptation, verification and promotion of solar cooling in Sunbelt region. At this moment commonly accepted appropriate methods and tools for benchmarking, assessment, and design for Sunbelt region are lacking. The main objectives of Activity C1 to address this issue are (Neyer, 2020):

- to document the tools and their specific applications,
- to provide measured data for validation of the tools, and
- to adapt the selected ones for sunbelt boundaries.

A systematic review was conducted to identify which solar cooling system design tools and models are reference in the published literature. The abstract and citation database selected is Web of Science (WoS) core collection. The query search string used is ALL=("solar cooling" OR "solar refrigeration") and the index dates cover are 1990/01/01-2021/06/30. The total of 1,216 documents (757 journal articles, 418 proceeding papers, 98 review articles, and 12 book chapters) were identified. A network visualisation diagram was generated in VOSviewer (van Eck & Waltman, 2010), version 1.6.16. In the network visualisation, items are represented by their label and circles. The size of the label and the circle (node) of an item is determined by the weight. The colour of an item is determined by the cluster to which the item belongs. Lines between items (nodes) represent links (van Eck & Waltman, 2020). Setting the minimum number of occurrences of a keyword to five, 301 keywords meet the threshold. Figure 1 shows the co-occurrence of keywords in the data set using different colours to show the clusters. Co-occurrence means that two aspects appear together in a document. The concepts behind the co-occurrence keywords are likely closely related (Callon, Courtial, Turner, & Bauin, 1983). From these keywords co-occurrences, a conceptual network structure of the research field can be built (Börner, Chen, & Boyack, 2003; Waltman, van Eck, & Noyons, 2010). 'Model' keyword is clustered with 'performance' and 'systems' and is linked with 'simulation. Keyword 'trnsys simulation', which has low occurrence, is the only software included. It is apparent from the network visualisation (Figure 1) that 'design tools' for solar cooling systems has not been a main focus investigated in solar cooling knowledge domain.

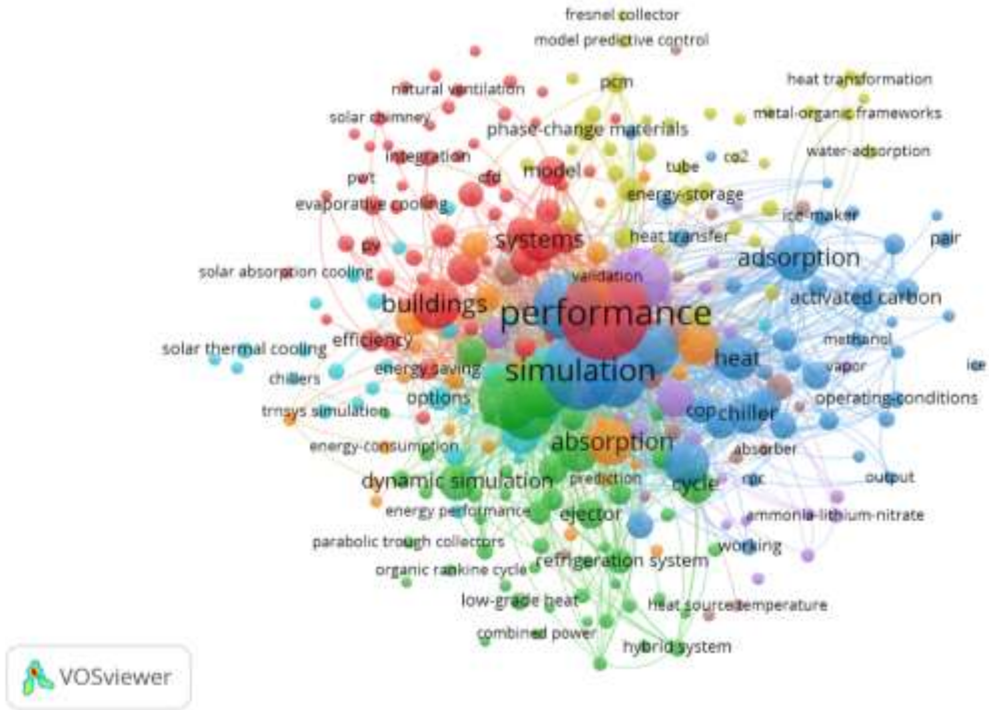

Figure 1. Network visualisation based on keyword co-occurrence analysis.

A query search string (“solar cooling”) (“design”) AND (“software”) in topic field produce 38 documents. Software tools applied are mentioned in 31 documents. The list of software tools shown in Table 2 were identified by a manual analysis.

Table 2. Software tools applied in solar cooling system research.

No.	Software tool	Reference
1	TRNSYS	(Uckan & Yousif, 2021)
2	MATLAB, EES	(Tashtoush & Nayfeh, 2020)
3	TRNSYS	(Mehmood, Maximov, Chalmers, & Friedrich, 2020)
4	TRNSYS	(Boero & Agyenim, 2020)
5	Meteonorm	(Alahmer, Wang, & Alam, 2020)
6	EES	(Al-Nimr, Tashtoush, & Hasan, 2020)
7	TRNSYS, MATLAB	(Aboelmaaref et al.)
8	EES, Ebsilon	(Tashtoush & Algharbawi, 2019)
9	TRNSYS	(Plytaria, Bellos, Tzivanidis, & Antonopoulos, 2019)
10	gPROMS	(Harraz, Freeman, Wang, Mac Dowell, & Markides, 2019)
11	TRNSYS	(Figaj, Szubel, Przenzak, & Filipowicz, 2019)
12	Sage	(Langdon-Arms, Gschwendtner, & Neumaier, 2018)
13	IES	(Hassabou & Khan, 2018)
14	TRNSYS	(Franchini, Brumana, & Perdichizzi, 2018)
15	EES	(Adibi, 2018)
16	EES	(Porumb, Porumb, & Balan, 2017)
17	EnergyPlus	(Ma, Saha, Miller, & Guan, 2017)
18	Sage	(Langdon-Arms, Gschwendtner, & Neumaier, 2017)
19	TRNSYS	(Brumana, Franchini, & Perdichizzi, 2017)
20	TRNSYS	(Vasta, Palomba, Frazzica, Di Bella, & Freni, 2016)
21	FLUENT	(Kalkan & Dagtekin, 2016)
22	TRNSYS	(Wang & Dennis, 2015)
23	TRNSYS	(Vasta, Palomba, Frazzica, Costa, & Freni, 2015)
24	TRNSYS, EES	(Tashtoush, Alshare, & Al-Rifai, 2015)
25	TRNSYS	(Lugo & Garcia-Valladares, 2015)
26	TRNSYS	(Gomez-Moreno, Palomar-Carnicero, & Cruz-Peragon, 2015)
27	IPSEpro	(Abdulrahim & Darwish, 2015)
28	TRNSYS	(Buonomano, Calise, & Ferruzzi, 2013)
29	TRNSYS	(Baniyounes, Rasul, & Khan, 2013)
30	TRNSYS	(Thomas & Andre, 2012)
31	TRNSYS	(Calise, 2011)

In general solar cooling system components are categorised in four processes: solar energy collection, cooling, distribution, and optional storage. Software tools are applied for estimating design parameters (by sizing tools) and predicting operational performance parameters (by simulation tools). It should be noted that the simulations tools could be used for design optimisations. Optimisations could aim for individual or combination of technical performance, financial performance, and environmental performance. Based on this knowledge we have developed a data collection proforma for design software tools; a brief version is shown in Table 3. A set of questionnaires with an extended version of Table 3 was developed and distributed to collect the information from 67 participants (Daborer-Prado, Neyer, & Aye, 2021). The idea of these questionnaires is to provide an insight about which tools and applications are being mostly used and implemented by the members of the Task 65. The analysis, results, and findings will be disseminated in a report, at the completion of the activity, to be published by the IEA.

Table 3. Proforma for solar cooling system design software tools

Purpose	Solar collector	Cooling technology	Distribution	Storage
Technical				
Financial				
Sizing				
Simulation				

Conclusions

IEA SHC Task 65 subtasks and their activities have been briefly described. The initial findings from the available literature on the software tools applied in solar cooling research also have been presented. It was found that TRNSYS is the most widely applied software tool relevant to solar cooling system design reported in the academic literature. The next step is to complete the collection of the data on design software tools utilised in the industry for practical installations. If you wish to participate and contribute to this data collection please contact us.

Acknowledgements

The funding provided from the Australian Renewable Energy Agency (ARENA) and the supports from the Australian Photovoltaic Institute (APVI) and the University of Melbourne are acknowledged. The funding of Austrian participation at the IEA SHC Task65 (FFG Project No. 883011) through the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) is gratefully acknowledged. This work has partially received funding from the German Federal Ministry for Economic Affairs and Energy (BMWi / PtJ) under grant agreement No. FKZ 03ETW024B (SorptionTakeOff).

References

Abdulrahim, H. K., & Darwish, M. A. (2015). Thermal desalination and air conditioning using absorption cycle. *Desalination and Water Treatment, 55*(12), 3310-3329. doi:10.1080/19443994.2014.939492

Aboelmaaref, M. M., Zayed, M. E., Elsheikh, A. H., Askalany, A. A., Zhao, J., Li, W. J., . . . Ahmed, M. S. Design and performance analysis of a thermoelectric air-conditioning system driven by solar photovoltaic panels. *Proceedings of the Institution of Mechanical Engineers Part C-Journal of Mechanical Engineering Science*, 14. doi:10.1177/0954406220976164

Adibi, T. (2018). Evaluation of using solar ammonia absorption cooling system for major cities of the Middle East. *International Journal of Heat and Technology, 36*(3), 840-846. doi:10.18280/ijht.360309

Al-Nimr, M. A., Tashtoush, B., & Hasan, A. (2020). A novel hybrid solar ejector cooling system with thermoelectric generators. *Energy, 198*, 17. doi:10.1016/j.energy.2020.117318

Alahmer, A., Wang, X. L., & Alam, K. C. A. (2020). Dynamic and Economic Investigation of a Solar Thermal-Driven Two-Bed Adsorption Chiller under Perth Climatic Conditions. *Energies, 13*(4), 19. doi:10.3390/en13041005

Baniyounes, A. M., Rasul, M. G., & Khan, M. M. K. (2013). Assessment of solar assisted air conditioning in Central Queensland’s subtropical climate, Australia. *Renewable Energy, 50*, 334-341. doi:10.1016/j.renene.2012.06.042

Boero, A., & Agyenim, F. (2020). Modeling and simulation of a small-scale solar-powered absorption cooling system in three cities with a tropical climate. *International Journal of Low-Carbon Technologies, 15*(1), 1-16. doi:10.1093/ijlct/ctz040

Börner, K., Chen, C., & Boyack, K. W. (2003). Visualizing knowledge domains. *Annual Review of Information Science and Technology, 37*(1), 179-255. doi:10.1002/aris.1440370106

Brumana, G., Franchini, G., & Perdichizzi, A. (2017). Design and Performance Prediction of an Energy plus Building in Dubai. In B. Fortunato, A. Ficarella, & M. Torresi (Eds.), *Ati 2017 - 72nd Conference of the Italian Thermal Machines Engineering Association* (Vol. 126, pp. 155-162). Amsterdam: Elsevier Science BV.

Buonomano, A., Calise, F., & Ferruzzi, G. (2013). Thermoeconomic analysis of storage systems for solar heating and cooling systems: A comparison between variable-volume and fixed-volume tanks. *Energy, 59*, 600-616. doi:10.1016/j.energy.2013.06.063

Calise, F. (2011). Design of a hybrid polygeneration system with solar collectors and a Solid Oxide Fuel Cell: Dynamic simulation and economic assessment. *International Journal of Hydrogen Energy, 36*(10), 6128-6150. doi:10.1016/j.ijhydene.2011.02.057

Callon, M., Courtial, J.-P., Turner, W. A., & Bauin, S. (1983). From translations to problematic networks: An introduction to co-word analysis. *Social Science Information, 22*(2), 191-235. doi:10.1177/053901883022002003

Daborer-Prado, N., Neyer, D., & Aye, L. (2021). *Milestone Report, Activity C1: Design tools and models, IEA SHC TASK 65 | Solar Cooling for the Sunbelt Regions*.

Figaj, R., Szubel, M., Przenzak, E., & Filipowicz, M. (2019). Feasibility of a small-scale hybrid dish/flat-plate solar collector system as a heat source for an absorption cooling unit. *Applied Thermal Engineering, 163*, 10. doi:10.1016/j.applthermaleng.2019.114399

Franchini, G., Brumana, G., & Perdichizzi, A. (2018). Performance prediction of a solar district cooling system in Riyadh, Saudi Arabia - A case study. *Energy Conversion and Management, 166*, 372-384. doi:10.1016/j.enconman.2018.04.048

Gomez-Moreno, A., Palomar-Carnicero, J. M., & Cruz-Peragon, F. (2015). Teaching different types of air conditioning systems using simulation software. In L. G. Chova, A. L. Martinez, & I. C. Torres (Eds.), *Inted2015: 9th International Technology, Education and Development Conference* (pp. 5183-5192). Valenica: Iated-Int Assoc Technology Education & Development.

Harraz, A. A., Freeman, J., Wang, K., Mac Dowell, N., & Markides, C. N. (2019). Diffusion-absorption refrigeration cycle simulations in gPROMS using SAFT-gamma Mie. In J. Yan, H. X. Yang, H. Li, & X. Chen (Eds.), *Innovative Solutions for Energy Transitions* (Vol. 158, pp. 2360-2365). Amsterdam: Elsevier Science BV.

Hassabou, A. M., & Khan, M. A. (2018). *Energy Efficient & Sustainable Buildings: Integration with solar assisted air-conditioning technology in Qatar - A Step towards Grid Free Zero Carbon Living*. Freiburg: Intl Solar Energy Soc.

IEA SHC. (2021). IEA Solar Heating & Cooling Technology Collaboration Programme. Retrieved from https://www.iea-shc.org/

Jakob, U. (2020). Task 65 new solar cooling project. *IEA SHC Newsletter, 71,* 11.

Kalkan, N., & Dagtekin, I. (2016). Passive cooling technology by using solar chimney for mild or warm climates. *Thermal Science, 20*(6), 2125-2136. doi:10.2298/tsci150608168k

Langdon-Arms, S., Gschwendtner, M., & Neumaier, M. (2017). Development of a solar-powered liquid piston Stirling refrigerator. In J. Yan, J. Wu, & H. Li (Eds.), *Proceedings of the 9th International Conference on Applied Energy* (Vol. 142, pp. 570-575). Amsterdam: Elsevier Science BV.

Langdon-Arms, S., Gschwendtner, M., & Neumaier, M. (2018). A novel solar-powered liquid piston Stirling refrigerator. *Applied Energy, 229*, 603-613. doi:10.1016/j.apenergy.2018.08.040

Lugo, S., & Garcia-Valladares, O. (2015). *Numerical simulation and experimental validation of a solar cooling system in Mexico*. Freiburg: Intl Solar Energy Soc.

Ma, Y. L., Saha, S. C., Miller, W., & Guan, L. (2017). Comparison of Different Solar-Assisted Air Conditioning Systems for Australian Office Buildings. *Energies, 10*(10), 27. doi:10.3390/en10101463

Mehmood, S., Maximov, S. A., Chalmers, H., & Friedrich, D. (2020). Energetic, Economic and Environmental (3E) Assessment and Design of Solar-Powered HVAC Systems in Pakistan. *Energies, 13*(17), 25. doi:10.3390/en13174333

Neyer, D. (2020). *1st Activity Meeting IEA SHC Task 65 Subtask C*. Presentation. IEA.

Neyer, D., & Jakob, U. (2020). *Solar Cooling for the Sunbelt Regions – a new IEA SHC Task*. Paper presented at the EuroSun 2020: 13th International Conference on Solar Energy for Buildings and Industry, Online.

Plytaria, M. T., Bellos, E., Tzivanidis, C., & Antonopoulos, K. A. (2019). Numerical simulation of a solar cooling system with and without phase change materials in radiant walls of a building. *Energy Conversion and Management, 188*, 40-53. doi:10.1016/j.enconman.2019.03.042

Porumb, R., Porumb, B., & Balan, M. (2017). Numerical investigation on solar absorption chiller with LiBr-H2O operating conditions and performances. In A. Anton, C. Balan, M. C. Balan, F. Bode, W. Bosschaerts, C. Croitoru, C. Inard, A. Meslem, I. Nastase, & M. Sandu (Eds.), *Sustainable Solutions for Energy and Environment, Eenviro 2016* (Vol. 112, pp. 108-117). Amsterdam: Elsevier Science BV.

Tashtoush, B., & Algharbawi, A. B. R. (2019). Parametric study of a Novel Hybrid Solar Variable Geometry Ejector cooling with Organic Rankine Cycles. *Energy Conversion and Management, 198*, 14. doi:10.1016/j.enconman.2019.111910

Tashtoush, B., Alshare, A., & Al-Rifai, S. (2015). Hourly dynamic simulation of solar ejector cooling system using TRNSYS for Jordanian climate. *Energy Conversion and Management, 100*, 288-299. doi:10.1016/j.enconman.2015.05.010

Tashtoush, B., & Nayfeh, Y. (2020). Energy and economic analysis of a variable-geometry ejector in solar cooling systems for residential buildings. *Journal of Energy Storage, 27*, 16. doi:10.1016/j.est.2019.101061

Thomas, S., & Andre, P. (2012). Numerical simulation and performance assessment of an absorption solar air-conditioning system coupled with an office building. *Building Simulation, 5*(3), 243-255. doi:10.1007/s12273-012-0060-0

Uckan, I., & Yousif, A. A. (2021). Investigation of the effect of various solar collector types on a solar absorption cooling system. *Energy Sources Part a-Recovery Utilization and Environmental Effects, 43*(7), 875-892. doi:10.1080/15567036.2020.1766599

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics, 84*(2), 523-538. doi:10.1007/s11192-009-0146-3

van Eck, N. J., & Waltman, L. (2020). *VOSviewer Manual: Manual for VOSviewer version 1.6.16*. Leiden: Univeristeit Leiden.

Vasta, S., Palomba, V., Frazzica, A., Costa, F., & Freni, A. (2015). Dynamic simulation and performance analysis of solar cooling systems in Italy. In A. Cocchi, P. Andreini, & L. Cassitto (Eds.), *69th Conference of the Italian Thermal Engineering Association, Ati 2014* (Vol. 81, pp. 1171-1183). Amsterdam: Elsevier Science BV.

Vasta, S., Palomba, V., Frazzica, A., Di Bella, G., & Freni, A. (2016). Techno-Economic Analysis of Solar Cooling Systems for Residential Buildings in Italy. *Journal of Solar Energy Engineering-Transactions of the Asme, 138*(3), 11. doi:10.1115/1.4032772

Waltman, L., van Eck, N. J., & Noyons, E. C. M. (2010). A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics, 4*(4), 629-635. doi:10.1016/j.joi.2010.07.002

Wang, X. L., & Dennis, M. (2015). Influencing factors on the energy saving performance of battery storage and phase change cold storage in a PV cooling system. *Energy and Buildings, 107*, 84-92. doi:10.1016/j.enbuild.2015.08.008