HPT Annex 56: Digitalization and IoT for heat pumps
Presentation of final results, 18th October 2023
WEBINAR - INSTRUCTIONS

➢ The webinar will be recorded and posted on the HPT Annex 56 website, [https://heatpumpingtechnologies.org/annex56/](https://heatpumpingtechnologies.org/annex56/)

➢ Please, mute your microphone and leave your camera off

➢ For technical support – contact Metkel Yebiyo metkel.yebiyo@ri.se (cc in the e-mail w link)

➢ If you have questions and comments during the presentations, please share them with all of us in the chat

➢ Questions will be answered during the Panel Q&A session in the end of the meeting
IEA Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Caroline Haglund Stignor, Heat Pump Centre

Research, Development, Demonstration, and Deployment of Heat Pumping Technologies
About Heat Pumping Technologies TCP

• A Technology Collaboration Programme (TCP) within the IEA since 1978
• An international framework of cooperation and networking for different HP actors
• A forum to exchange knowledge and experience
• A contributor to technology improvements by RDD&D projects

20 member countries

Austria, Belgium, Canada, China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, South Korea, Spain, Sweden, Switzerland, United Kingdom, United States

www.heatpumpingtechnologies.org
Heat Pumping Technologies

Includes

- Heating and cooling
- Air conditioning
- Refrigeration

Covers applications in

- Residential and commercial buildings
- Industries
- Thermal grids in cities and communities
- Other applications
HPT TCP Organization and Management

- **Executive Committee**: The board of HPT TCP - one vote per member country
- **National Teams**: Organizations representing national HPT activities. A forum for discussion networking and creation of new ideas. Meet at joint National Experts meetings.
- **The Heat Pump Centre**: The central program office and communication center of HPT TCP
- **Annexes**: Elaborating new knowledge through collaborative RDD&D work
The Heat Pump Centre

Information dissemination and communication
- Publications (e.g. project reports)
- HPT Magazine and Newsletter (digital)
- Website www.heatpumpingtechnologies.org
- Social media: LinkedIn, Twitter (@heatpumpingtech) and WeChat

Program Support
- to ExCo, NTs and Project leaders (OAs)

And
- Generation of new activities
- National Experts meetings
- Support to IEA publications
- Outreach activities
Heat Pumping Technologies Magazine and Newsletter

Selected Topics for 2023
Every issue covers both topical and non-topical articles

- **Industrial Heat Pumps - Opportunities to unlock the full potential of heat pumps** Published: March 31

- **Report from the 14th IEA Heat Pump Conference**
  - Published: September 08, released via Newsletter

- **Heat pumps in district heating and cooling energy grids**
  - Release date: December 08

Click here to Subscribe
Annex 56
Heat Pumping Technologies TCP
DIGITALISATION AND IOT FOR HEAT PUMPS - IEA HPT ANNEX 56

Project duration: 01/2020 – 12/2022

Participants:

- Austria: AIT Austrian Institute of Technology (OA), TU Wien, University of Applied Sciences Burgenland, Austrian Academy of Science
- Denmark: Danish Technological Institute, Technical University of Denmark, Energy Machines ApS
- France: EDF
- Germany: Fraunhofer Institute for Solar Energy Systems ISE, RWTH Aachen
- Norway: SINTEF
- Switzerland: Hochschule Luzern
- Sweden: RISE, KTH
# Digitalisation and IoT for Heat Pumps - IEA HPT Annex 56

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- Reinhard Jentsch
- Philipp Ortmann
- Christoph Reichl
- Veronika Wilk
- Bernd Windholz
- Gerhard Zucker
- Goran Music
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- Markus Lindahl
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- Metkel Yebiyo

## France
- Odile Cauret
DIGITALISATION AND IOT FOR HEAT PUMPS - IEA HPT ANNEX 56

- interviews and surveys on the state of digitalisation in the participating countries
- ca. 40 factsheets of IoT use cases and projects
- household and industrial heat pumps
- analysis of similarities and differences

https://heatpumpingtechnologies.org/annex56
DIGITALISATION AND IOT FOR HEAT PUMPS - IEA HPT ANNEX 56

https://heatpumpingtechnologies.org/annex56
Annex 56: Digitalization and IoT for Heat Pumps

Task 1: State of the art

Presented by
Davide Rolando, KTH

DOI 10.23697/cf03-v605
Task 1: State of the art

Internet of Things: “Machine-to-machine communications and person-to-computer communications will be extended to things, from everyday household objects to sensors monitoring the movement of the Golden Gate Bridge or detecting earth tremors. Everything from tyres to toothbrushes will fall within communications range, heralding the dawn of a new era, one in which today’s internet of data and people gives way to tomorrow’s Internet of Things.” (ITU, 2005)

(Statista, 2019)
Task 1: State of the art

Industrial Ethernet fieldbuses: Modbus, KNX, BACnet, …

Session layer protocols: AMQP, MQTT, …
Task 1: IoT use cases

44 use cases collected
• Products and services (19)
• Research projects (25)

Categories
• Heat pump operation optimization
• Predictive maintenance
• Flexibility provision
• Heat pump operation commissioning
• Heat as a service

Factsheets available on the IoT Annex website
“Heat Pump of the future: smartness and connectivity”

- What is a smart heat pump?
- Which technologies for smart heat pumps?
- Perspectives: Connectivity and sources optimization

Based on a study by Association Française pour les pompes à chaleur (AFPAC)
Task 1: Manufacturer survey (Austria)

About 50 questions to gather and evaluate the general sentiment on the importance of IoT

A total of 16 companies participated in the survey

Challenges
• Data security
• Data protection guidelines
• Increase of system complexity
• Availability of qualified personnel
Task 1: Expert interviews (Sweden)

Expert interviews involving leading heat pump manufacturers, IoT companies, associations, and consultants.

Opportunities:
• Innovative business models
• Predictive maintenance

Challenges
• Lack of guidelines
• Need for demonstrators

Motivation to introduce IoT products in heat pump systems
• Reduce operating cost
• Service and repair improvement
**Thank you!**

## Task 1: contributors

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<tr>
<th>Country</th>
<th>Institution</th>
<th>Contributors</th>
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IoT Annex 56 webinar

Task 1: State-of-the-art
3 case examples from Denmark

Jonas L. Poulsen, DTI
18-10-2023
DANISH WORKING GROUP – ANNEX 56

- Danish Technological Institute, Refrigeration and Heat Pump Technology – National working group lead

- DTU Construct, Department of Civil and Mechanical Engineering - Research partner

- DTU Compute, Department of Applied Mathematics and Computer Science – Research partner

- Energy Machines - Designs and builds integrated energy systems
23 DANISH CASE DESCRIPTIONS

Product and Service Suppliers:
- Energy Machines – Energy machines verification
- Neogrid – PreHEAT for Heat Pumps by Neogrid Technologies ApS
- LS Control - SmartConnect Center
- Centrica Energy Marketing and Trading
- Climify – Indoor Climate Monitoring Platform
- Nærvarmeværket – Community owned Heat Pump Company
- AI-nergy – Artificial Intelligence Assisted Products
- ENFOR A/S – Energy Forecasting and Optimization Platform
- Center Denmark – The Digital Data Platform
- EnergyFlexLab
- METRO THERM - MyUpway™

IoT Project Cases:
- Digital Twins for Large-scale Heat Pump and Refrigeration Systems
- EnergyLab Nordhavn - Smart Components
- Flexheat – Intelligent and Fast-regulating Control
- Smart-Energy Operating-Systems (SE-OS) framework
- OPSYS 2.0
- Cool-Data
- SVAF phase II
- HPCOM
- Flexible Energy Denmark
- Res4Build
- Development of Fast Regulating Heat Pumps using Dynamic Models
- CEDAR

11 case descriptions for product and service providers and 12 case descriptions for R&D projects about IoT and digitalization of heat pumps in Denmark. Full descriptions available on homepage: https://heatpumpingtechnologies.org/annex56/factsheets/
The Energy Machines Verification tool (EMV) is a combined hardware/software solution based on physical measurements, a service REST API, and thermodynamic models of the heat-pumps.

- Provides online/live transparent performance monitoring, as well as basis for predictive maintenance. Transparency between supplier and customer.
- Data security: All services use encrypted protocols (TLS/HTTPS) when exchanging data from client to server.
- Quality-of-Service: Data measured every minute and results also provided every minute (real-time).

EMV dashboard with quick overview of current performance.

Energy Machines heat pump installation with sensors placed inside the boxes.
DIGITAL TWIN (PROJECT)

- **Advanced system monitoring**
  - Performance benchmarking
  - Analysis of functionality and performance
  - Validity check
  - Soft sensors

- **Fault detection and diagnosis**
  - Fault mechanism monitoring incl. early-stage warning and predictive maintenance
  - Model-based interpretation of system alerts

- **Optimized system operation**
  - Continuous set-point tuning
  - Scheduling of production and downtime

**Concept for services in the Digital Twin project.**
Examples:

- Optimization framework for continuous set-point optimization of e.g. the compressor speeds for optimizing COP in heat pumps for district heating. Based on dynamic model of the system.

- Adaptive model-based monitoring for a large-scale heat pump prone to fouling, can be used to simulate and investigate cleaning-in-place (CIP) implementation.
ENERGYLAB NORDHAVN – SMART COMPONENTS (PROJECT)

- Special focus on heat recovery unit integrated into the refrigeration system of a supermarket and supplied to the local district heating grid or to the building itself.

- Studies on supply of cooling to the supermarket and heating to the district heating system by adaption of the gascooler pressure. Furthermore, control of the heat recovery system according to dynamic price signals were demonstrated.

- Maximizing the revenue for the supermarket owner by an optimal real-time decision on selling the recovered heat. Payback period of 3-4 years.

Heat is recovered from a supermarket refrigeration system.

Sketch of the communication framework used for demonstration of the control of the heat recovery unit according to dynamic price signals.
Task 2 – Interfaces, Platforms and Protocols

presented by Reinhard Jentsch, AIT
• Task 2: Provision of communication and processing capabilities
• Focus on heat pumps by looking at examples
  • Commonalities, Challenges, Solutions

• Completing a circle adds values
  • Various time scales possible
  • Indirect inference and action possible
DIGITAL TWINS OF HEAT PUMPS

• Challenges
  • Distributed data
  • Timescales
  • Simulation req.
  • Configuration

• Solutions
  • Data Broker (MQTT)
  • Containers
  • FMU
  • Frameworks

Source: Task 2 - Report Digital Twins for Large-scale Heat Pumps and Refrigeration Systems Example
Heat pump is part of a connected system

- **Challenges**
  - Heterogeneity and Complexity
  - Data Volume
  - Data Security and Protection
  - Level of Control
  - Proprietary Protocols

- **Solutions**
  - Semantic Data Representation (BACnet)
  - Gateways
Heat pump is part of the public power grid. The service provider is an outside entity

- **Challenges**
  - Security
  - Retrofit and interoperability
  - Levels of user engagement low

- **Solutions**
  - Interface definition and standardisation
  - All in one-Solutions
Heat pumps are in use for decades. Requirements change. Additional features are requested

- **Challenges**
  - Legacy and proprietary communication capabilities
  - Structural conditions
  - Maintaining core functionality

- **Solutions**
  - Wireless connections
  - Layered approach
  - Field level ➔ Gateway ➔ IoT Integration
SUMMARY AND CONCLUSIONS

- Sensors, hardware and software
  - available
  - solvable

- Complexity of Systems
- Heterogeneity and Retrofit
- Security
  ➔ High integration effort
  - Standards
  - Frameworks
  - Semantic representation

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<th>Least challenging</th>
<th>Most challenging</th>
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- Availability of suitable hardware
- Higher cost of IoT-enabled products
- Availability of suitable software
- Availability of communication interfaces and protocols
- Application of analysis methods and appropriate modeling
- Legal framework
- Lack of standardization, norming and recommendations for action
- Availability of qualified personnel
- Increasing complexity
- Acceptance by customers
- Requirements in the area of data protection
- Data security requirements

ZEB Laboratory
BAC in Action

Connected heat pumps as part of BACs
Kristian S. Skeie, SINTEF Community
IoT Annex Webinar, 18th October 2023
The ZEB laboratory is a
- 1700 m² office & university building
- ZEB COM (Construction, operation, materials)

An arena where
- new and innovative materials and technologies are developed, investigated and tested
Energy concept

- ZEB COM (Construction, operation, materials)
- Energy flexibility and integration of local production
  - Connected to campus district heating and electricity ring
  - Roofs and facades clad with PV (<150,000 kWh/yr)
  - 2 air to water heat pumps (2x16kWh with R290)
  - Low temp. hydronic heating w./acc. tank
  - PCM tank with bio-wax ~37 °C (200 kWh)

Optimized operational setpoints
Predictive maintenance
System monitoring & diagnosis

https://wiki.zeblab.no/
In the ZEB Lab, the data acquisition system is centred around a time-series DB.

The hardware abstraction follows a three layer architecture:

- Building automation controllers are polled over the BAC network.
- Data ingestion by “BACnet2Influx” Python script (on-site gateway).
- InfluxDB is utilized to combine data from other IoT sources too.

A challenge to interpret large amounts of data, and combine data with different resolutions, e.g. from the heat pump loop.
Using a central data storage can help streamline the development of new services.

- **Ext. web-services**
  - Applications
  - Data Storage
  - Hardware I/O

- **Resources (Hardware I/O)**
  - Automation controller (Desigo PXC): BACNET
    - Heat pump: Modbus RTU
    - Electricity meters: Modbus
    - Heating meters: MBUS
  - Room controllers (Desigo PXC3): BACNET
    - Thermostats, room sensors etc.

- **Time-series**
  - Queries (Flux)
  - InfluxDB platform
  - BACnet2Influx

- **Models**
  - Input
  - Option to write back results to DB

- **Outputs**
  - Option to interface directly with HW

- **Ability to visualize data in near real-time**
  - Jupyter notebooks, Grafana or Influx dashboards

- **Writing model results back to the DB**
  - or data from external APIs such as weather forecasts

- **Writing setpoints back to the system with**
  - our «BACforsk» based on BAC0 Python library (UDP)

Using a central data storage can help streamline the development of new services.
The need to represent and connect various data sources in a unified way

Combined monitoring data & physical information to:
- Analyze heat pump operation in real-time
- Model the heat pump COP and output
- Model the building heating demand and PV system

The physical information required comes from:
- Influx tags (generated from BACnet codes and documents)
- Design documentation (heat pump & PV manufacture data)
- As-built documentation (building energy calculations)
How meta-data are stored today

- Meta-data are written into Influx from an Excel spread sheet
- stored as key-value pairs which can be used to build InfluxDB queries
- naming according to a universal labeling scheme used in Norway (Statsbyggs TFM)

**Example:**

\[ +338=360.001-JV401 \]

**Supply Fan in Air Handling Unit 1**
How meta-data are stored today

• Meta-data are written into Influx from an Excel spread sheet
• stored as key-value pairs which can be used to build InfluxDB queries
• naming according to a universal labeling scheme used in Norway (Statsbyggs TFM)

**From this information we can build the following query:**

**Example:**

\[ +338 = 360.001 \]

SUPPLY FAN IN AIR HANDLING UNIT 1
How meta-data could be stored in the future

- BACnet to Brick model from a BACnet network, and then augment the basic model with metadata.
- Developments like NREL’s building Metadata Ontology Interoperability Framework (BuildingMOTIF)
Lessons learned from using the time-series DB for application development

Writing model results back to the same time-series platform has tremendous value
Semantic metadata in the form of key-value pairs stored onto InfluxDB from Excel/BACnet is a start
New methods to create, store, and validate metadata from BACnet messages (and BIM) should be explored

Future developments of BACnet2Influx and BACforsk applications:
Lower tier: Focus on building predictable and robust data-processing pipelines
Upper tier: More specialized APIs since Influx Python client and Flux queries are not always suitable
Task 3 – Data Analysis

Tim Rist

IEA HPT TCP Annex 56 – IoT for Heat Pumps
Results webinar, online, October 18th 2023

www.ise.fraunhofer.de
Goals of Task 3

»Data analyses leverage collected data from IoT devices to gain new insights and optimize operation«
Goals of Task 3

- Discussion of data analysis aspects from national projects
- Collection of use cases for applications of data analyses
- Categorization of data analysis methods
- Discussion on boundary conditions for the application of data analysis methods
Contents

- Best practices on...
  - Pre-treatment of data
  - Usage of data models, meta data and Building Information Models (BIM)

- Applicability of data analysis methods in buildings

- Overview on data analysis use cases in the Annex project
  - Used data analysis methods
  - IoT aspects
Categorization of data analysis methods

- Heat pump operation optimization
- Predictive maintenance
- Flexibility provision
- Heat pump operation commissioning
- Heat as a service

- Fault detection
- Predictive maintenance
- Optimization
- Control engineering
- Comparison to other heat pumps

- Visualization and manual analysis
- (Analysis of) alarms
- KPI calculation and comparison
- Forecasting
- MPC
- MILP
- Big data analysis
- Data model development
- Machine learning
Task 3 Report

Use case categorization

- Comparison of 16 out of 44 use cases concerning
  - Used analysis methods
  - Use of models (data driven, simulation, ...)

- Categorization of use cases

  ➢ Provide hints on applicable data analysis methods for certain use cases
Thank you for your attention!

—

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Danny Günther
Tim Rist

AIT Austrian Institute of Technology
TU Wien
Danish Technological Institute (DTI)
SINTEF Community
Fraunhofer ISE
Fault detection in refrigeration cycles

Annex 56
Experimental Infrastructure
Urban Energy Lab

- Emulation of dynamic test conditions possible
  - Hardware-in-the-loop
  - Weather scenarios
  - User profiles in residential applications

- Safe test environment
  - Monitoring of the gas concentration using sensors
  - Automated extraction system

- Integrated test benches
  - Compressor
  - Expansion Valve
  - Air-to-Water Heat Pump
Heat Pump Test Bench
Development of a refrigeration cycle with measurement components

Indoor Unit
Outdoor Unit

CAD models and complete test setup of indoor and outdoor unit of the heat pump test bench.
Heat Pump Test Bench
Development of a refrigeration cycle with measurement components

- **Refrigerant Cycle**
  - Speed control of compressor and fan
  - Electronic expansion valves
  - Heating and cooling mode

- **Measurement technology**
  - Pt100 temperature sensors
  - Piezoresistive pressure sensors
  - Coriolis flow meter

- **Emulation of Faults**
  - Heat Exchanger Fouling
  - Over-/Undercharge
  - Charge Variation and Migration
  - Oil Circulation

P&I flowchart of the heat pump test bench, which allows the emulation of typical faults. [Klebig (2022) - GLC]
Fault Emulation and Detection
Evaporator Fouling

- Evaporator Fouling
  - Covering of Heat Exchanger
  - Reducing Fan speed

- Training of ANNs
  - Positive Sample
    - Pre-Training of known faults
    - Features with high sensitivity to fault condition
      - $P_{suct}, T_{suct}$
      - 85% prediction accuracy
  - Negative Sample
    - Pre-Training of fault-free data
    - Features with no sensitivity to fault condition
      - $P_{el}, T_{amb}, T_{condenser, out}$
      - 95% prediction accuracy

Emulation of "fouling" and detection based on pre-trained fault conditions using temperature and pressure features. [Klebig (2022) - DKV]
Summary and outlook

- Emulation and Measurement of various fault conditions
- Improvement of automated Fault Detection and Diagnostics
- Support for the maintenance staff
Thank you for your attention!

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Task 4 – Business models

presented by Veronika Wilk, AIT
TASK 4 – BUSINESS MODELS

- 19 examples of business models
- SWOT analysis to compare IoT enabled with traditional business model
- multiple stakeholders
- new business models for
  - HP operation optimization
  - predicative maintenance
  - flexibility provision
  - heat as a service
SWOT Analysis

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<th>negative</th>
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<td>internal</td>
<td>Strengths</td>
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<tr>
<td>external</td>
<td>Opportunities</td>
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- Predictive maintenance vs. Fixed interval or on demand maintenance
- Heat as a services vs. Traditional model
- Providing flexibility with heat pump pooling vs. Using a heat pump as an autonomous component in a building
BUSINESS MODELS

- value proposition for the consumers:
  - lower costs, higher efficiency, higher reliability

- heat pump value chain (component and heat pump manufacturers, vendors, installers):
  - new products and services
  - more responsibility for efficiency than in traditional business models

- energy system (aggregators, suppliers, grid, etc.):
  - strong need for flexibility to compensate for fluctuating generation
  - sector coupling with heat pumps (power/heat),

- ESCO:
  - help to spread heat pumps as their service requires less involvement of the consumers
IoT Annex 56 webinar

Task 4: Business models
3 case examples from Denmark

Jonas L. Poulsen, DTI
18-10-2023
Visualization of supplier groups and examples of associated suppliers in an IoT-based energy system for heat pumps – based on review results from collected case studies.

- Several stakeholders at different levels in the heat pump industry are focusing on enhancing and deploying digital and IoT-enabled solutions for heat pumps in Denmark.

- Cooperation between groups important to further develop the digitalization of the energy system around the heat pump(s).

- Overlap for companies being present in more groups, but general grouping visualized (various other companies not included in review also exists).
Example for operation optimization for heat pumps in buildings is the PreHEAT heat pump controller by Neogrid.

Purpose of PreHEAT is to save energy and reduce the cost of heat, by optimizing the heat pump operation in relation to demanded energy from the building and local electricity prices and tariffs. Saves energy without compromising indoor comfort requirements.

Sensor data like indoor temperature, consumed electricity and delivered heat are collected and sent to the Neogrid PreHEAT Cloud.

Neogrid provides several services: model predictive control (MPC) of the heat pump via the cloud, the use of variable prices and aggregator-based services for different electricity markets possible.

Swarm controller in operation (allowing/blocking the individual heat pump operation to provide an overall behavior of the pool, still complying with heat pump constraints).
The platform myUpway™ provides online monitoring and control services, including surveillance of heat pumps energy consumption and fault alarms as well as remote control possibilities (Metro Therms version of the parent company NIBE's online service platform Uplink™).

Operation optimization possible through information from electricity grids and users’ consumption patterns to minimize operational costs of heat pumps (feature named “Smart Price Adaption”).

Service providers connected to myUpway™ can avoid unnecessary physical assistance to heat pump users and get remote assessment of multiple units.
FLEXHEAT (PROJECT)

- Grid services are provided with a flexible energy system consisting of an 800 kJ/s ammonia-based ground-water heat pump with reciprocating compressors, 200 kJ/s electric boiler and a thermal storage tank of 100 m³.
- System is optimized by a linear-optimization model supported by a dynamic model of the heat system to schedule optimal planning production with a real-time communication setup to control the heat pump accordingly. Furthermore, the heat pump has been modified to provide fast regulation services to the grid.
- Preliminary results indicate that operating costs can be reduced by 7 % by introducing intelligent operation with the linear optimization model, and an additional 6 % costs reduction can be achieved by delivering grid services.

Flexible heat production during winter [HOFOR, 2021].
New Annex idea: Digital services

• how to make use of digital services for heat pumps?
• online workshop tomorrow at 09.15 – 10.45 to draft the idea and the legal text
• if you are interested to join, register here:
  https://comm.ri.se/b/v?event=1982&ucrc=20A7F5F7F8

INTERESTED IN JOINING AN ANNEX?

https://heatpumpingtechnologies.org/annex56
DIGITALISATION AND IOT FOR HEAT PUMPS - IEA HPT ANNEX 56

https://heatpumpingtechnologies.org/annex56
What was your take away message from today’s webinar?