INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1900-TRP, "Using simulated weather data with sparse measured data to produce hourly weather files and calculate design conditions"

Attached is a Request-for-Proposal (RFP) for a project dealing with a subject in which you, or your institution have expressed interest. Should you decide not to submit a proposal, please circulate it to any colleague who might have interest in this subject.

Sponsoring Committee: TC 4.2 Climatic Information
Co-sponsored by: N/A

Budget Range: $90,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: **April 1, 2022** or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EST, December 15, 2021. NO EXCEPTIONS, NO EXTENSIONS. Electronic copies must be sent to rpbids@ashrae.org. Electronic signatures must be scanned and added to the file before submitting. The submission title line should read: 1900-TRP, "Using simulated weather data with sparse measured data to produce hourly weather files and calculate design conditions", and *"Bidding Institutions Name"* (electronic pdf format, ASHRAE's server will accept up to 10MB)

If you have questions concerning the Project, we suggest you contact one of the individuals listed below:

For Technical Matters
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Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research and Technical Services, (MORTS) by December 1, 2021 in order that any late or additional information on the RFP may be furnished to them prior to the bid due date.

All proposals must be submitted electronically. Electronic submissions require a PDF file containing the complete proposal preceded by signed copies of the two forms listed below in the order listed below. **ALL electronic proposals are to be sent to rpbids@ashrae.org.**

All other correspondence must be sent to ddaniel@ashrae.org and mvaughn@ashrae.org. Hardcopy submissions are not permitted. **In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EST, December 15, 2021. NO EXCEPTIONS, NO EXTENSIONS.**

The following forms (Application for Grant of Funds and the Additional Information form have been combined) must accompany the proposal:

(1) ASHRAE Application for Grant of Funds (electronic signature required) and
(2) Additional Information for Contractors (electronic signature required) ASHRAE Application for Grant of Funds (signed) and

ASHRAE reserves the right to reject any or all bids.

State of the Art (Background)

Reanalysis weather data

RP-1745 and RP-1561 have introduced ASHRAE to the basics of simulated climate data, either reanalyses using climate forecasting models (RP-1745) or mesoscale modeling (RP-1561) to downscale from the 30–50 kilometer grid in reanalysis to a finer grid of 3–5 km. In RP-1745 (Roth 2019), the design conditions from reanalysis were compared to those using measured data for all the locations in the ASHRAE HOF, while a subset of hourly weather files based on reanalysis was compared to those from measured data for 15 representative ASHRAE Climate Zones. Although the study showed good promise for such synthetic climate data, it also revealed various shortcomings in matching measured data, due partly to resolution and partly to limitations in the modeling, that caused significant differences in locations in coastal or mountainous areas, as well in certain regions of the world such as India or Australia. In RP-1561 (Qiu, Roth, et al. 2016), the WRF (Weather Research and Forecasting) mesoscale model, widely used by atmospheric research and forecasting, was customized to ASHRAE's needs and used to model the weather in four US regions. In the context of this project, mesoscale modeling can be seen as a method to downscale dynamically from reanalysis to a local area (4km×4km or less). Mesoscale modeling was found to be very computationally intensive, making it highly unlikely that an engineer or even climate consultant would do such simulations to meet the needs of a project. In all likelihood, for both reanalysis and mesoscale modeling, the viable approach would be to access various databases such as MERRA, CFSR, etc. Reanalysis models are continuously refined in terms of accuracy and resolution. For example, the most recent reanalyses from ECMWF (CAMS and ERA5) have a better spatial resolution than MERRA2. This should improve accuracy, particularly over mountainous areas, at the expense of an ever-increasing data volume. Depending on the database, simply downloading and processing the data can still require considerable time and effort, so the usage of synthetic weather data will probably remain in the realm of the expert or dedicated user.

Sparse Weather Data Sets

Sparse weather data sets refer to any measured weather data that are not hourly or at least at a frequency of every three hours by which simple interpolation can be used to fill in the missing hours (Matsuo 1984). These can be grouped into two broad categories: (1) historical records at the daily level, such as max/min values often only of temperature, as found in US second-order stations, daily averages in US third-order stations, or sub-daily values of various formats and parameters found in reports around the world; and (2) monthly statistics, at best of average daily extremes of temperature, average humidity and wind speed, or at worst only average daily extremes, i.e., max/min temperatures. The sheer amount of such sparse data sets is intriguing. For example, NOAA's NCEI (National Center for Environmental Information) states that their Global Historical Climate Network Daily (GHCN-Daily) contains records from over 100,000 stations in 180 countries and territories, whereas the number of stations in the Integrated Surface Database (ISD) with adequate hourly records for ASHRAE Handbook design tables is around 10,000. Of particular interest to ASHRAE members working in the US is that the GHCN-Daily contains over 20,000 stations, many with decades of reliable data. Various researchers have explored various methods to develop hourly data from sparse data sets (Degelman 1991 and 2004, Hansen and Driscoll 1977, Hittle and Pedersen 1981, Balcomb 1999, Phillips 1984, Hokoi et al. 1990, Bradshaw and Salazar 1985), and TC 4.2 developed a work statement in 2011 (WS-1494, "Procedures to Generate Hourly Climate Data from Sparse Data Sets") that was not approved. Consequently, sparse data sets have remained an untapped voluminous source of data. These datasets may include a heterogenous blend of manual versus automatic, synoptic versus aviation, Fahrenheit versus Celsius, as well as integer-rounding versus tenth-degree precision. These issues result in inconsistent precision, which together with missing observations, requires local expert judgement to assure if ground-truth reasonably represents the coincident dynamics of temperature and humidity. Consequently gridded 4-dimensional meso-scale products such as Weather Research Forecast (WRF) should be used if available, as is available in the regions of Denver, New York, San Francisco, and Orlando (RP-1561).

Combining reanalysis data with sparse data sets

Combining simulated weather data (climate reanalysis and/or mesoscale modeling) with sparse weather data sets is intriguing because the different strengths of the two types of weather data can compensate for each other's weakness. Simulated weather data is very comprehensive but of uncertain reliability for specific locations, while measured data is often spotty but may be of good reliability when available.

Reanalysis data can also be used to improve the quality and coverage of detailed, i.e., non-sparse, weather data. Many of these, in particular those at the lower end of data quality, may have long periods of missing data or are of short duration. Prior to the emergence of reanalysis models and databases, there was little that could be done to fill the gaps or extend the data except by repeating the last available daily series. Since reanalysis provides an uninterrupted simulated record of climate conditions extending back decades, it may provide a much more credible method for filling missing data or extending the time period of the measured data back into the past.

Figs. 1 and 2 show how the two data types can be complementary, using the case of a station in Nepal with poor measured data. When the recorded and simulated (MERRA2) data are plotted together, there is a very noticeable bias with the simulated data peaking roughly 8–10°C lower.

Fig. 3 Measured and MERRA2 bias-adjusted Dry Bulb Temperatures in Jumla Nepal WMO 444240 Jan 2014

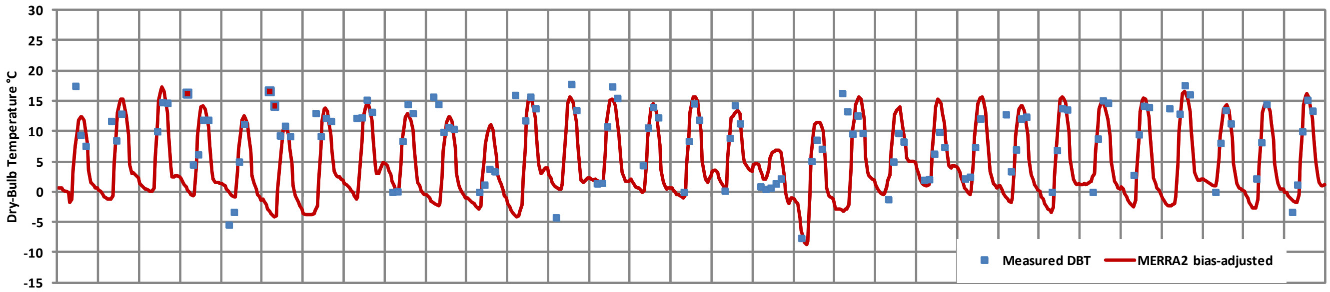
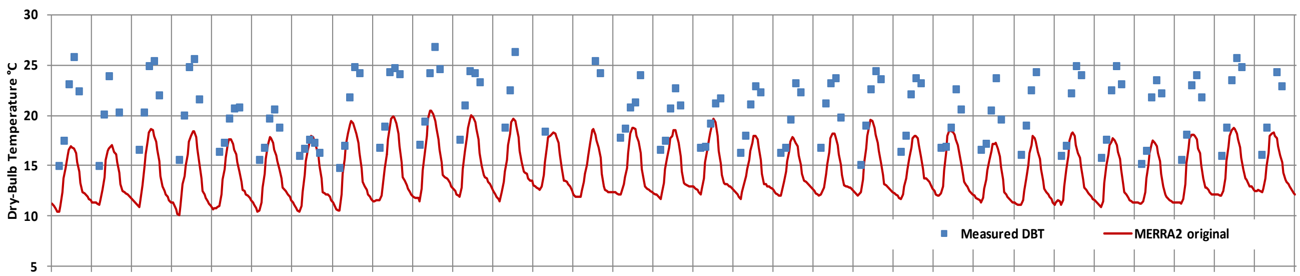


Fig. 2. Measured and original MERRA2 Dry Bulb Temperatures in Jumla Nepal WMO 444240 Jul 2014



However, by adding two simple monthly bias corrections for average temperature and temperature range, the two data streams come much closer together, especially in July (Figs. 3 and 4). Incidentally, the reanalysis data set also provides a way to weed out suspect measured data, as shown by the data for Jan. 4 and 6 that peak in the predawn morning hours (see red dots below).

Fig. 3 Measured and MERRA2 bias-adjusted Dry Bulb Temperatures in Jumla Nepal WMO 444240 Jan 2014

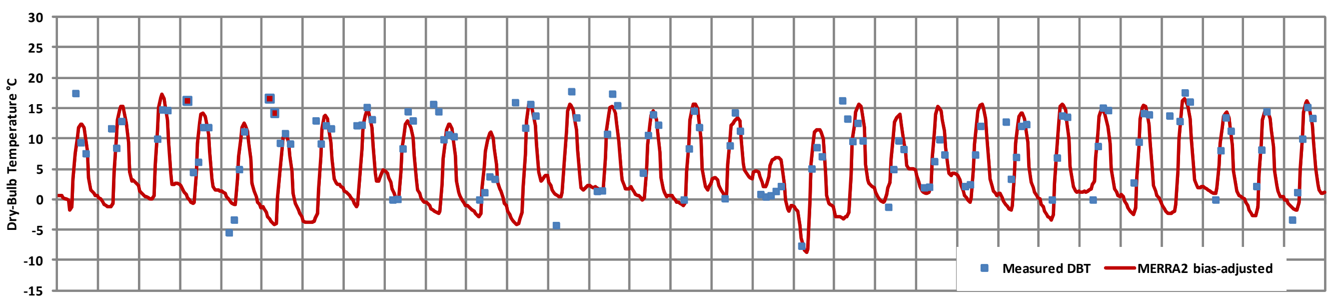
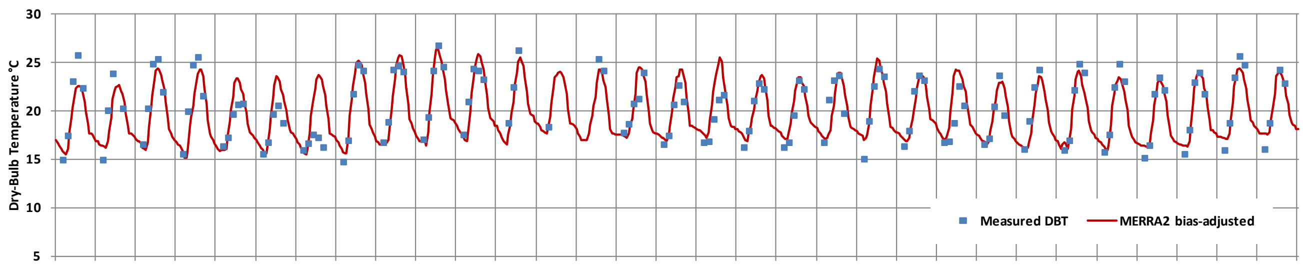


Fig. 4 Measured and MERRA2 bias-adjusted Dry Bulb Temperatures in Jumla Nepal WMO 444240 Jul 2014



Justification and Value to ASHRAE

Residential and commercial building sector accounts for approximately 28% of the total US energy consumption (EIA 2020). The potential to reduce energy use through retrofit and retro-commissioning programs is estimated to be 43% or more (DOE 2020). As new energy codes and standards, e.g., ASHRAE Standard 90.1, 90.2 and 189.1, have increased the stringency on lighting power densities and internal loads, the fraction of the heating and cooling loads due to climatic variables has dramatically increased. The climate-induced loads only accounted for a small fraction of a commercial building's cooling loads in the pre-energy codes days, but they can now account for as much as 65% of the cooling load and an even higher fraction of the heating load. This has resulted in the need for more accuracy in the representation of the exterior ambient conditions on an hourly basis.

ASHRAE has taken a visible and important role in building energy modeling (to wit, its certifications in BEAP, BEMP and HBDP). Research efforts that support simulation modeling will provide ASHRAE with invaluable help in this endeavor. In the climatic data area, ASHRAE has developed and published the Design Condition tables in the HOF and the WYEC2 set of 3,012 typical weather files for international locations (Roth 2013, Huang 2012).

These efforts have provided a framework and tools for analyzing building energy use, but they need to be supported by good, reliable climatic data inputs. In order to regularly use predictive energy models, reliable climatic data will always be necessary. Being able to generate hourly climatic data for sites that are not included in the TMY3 or IWEC2 data sets will be a boon for energy simulation progress within the ASHRAE membership (NREL 2005). The methods developed under this research project will result in a tool that is faster, more economical, and more reliable than ad hoc "guesswork" techniques currently used by engineers when climate data for their building site is unavailable.

Objectives

The purpose of this follow-on effort to two previous ASHRAE projects on computer simulated weather data (RP-1745 and RP-1561) is to combine the outputs from such methods with sparse measured data for test cases to produce design climatic data and to produce hourly time-series data, that can then be used to determine the accuracy of the results, the level of effort required, and the potential increase in the number of locations that can be included if the method were used for all regions of the world. The underlying assumption is that climate reanalysis models correctly represent the overall physics and dynamics of the atmosphere, but can benefit significantly by tuning against limited measured data. The tests will determine how much limited data is sufficient at what required accuracy. These tests are similar in approach to calibrated building energy simulations, with which ASHRAE members are more familiar. However, in this instance, the calibration is done on the outputs, not on the inputs nor models, which would be much more difficult.

Each of the tests will have three related but distinct objectives:

1) By using actual sets of sparse data for a region (state, country, etc.), the tests will estimate how many additional locations can have adequate hourly data produced, as compared to the locations currently available in the ASHRAE HOF tables.

2) By taking specific locations that have detailed hourly data within the region, and by reducing that database to sparse data sets, the test will determine the accuracy of the proposed hybrid method.

Lastly, the design conditions or hourly time-series that are developed will be evaluated qualitatively for reasonableness and distributed as a supplement to the ASHRAE HOF tables.

Scope:

Describe in a manner that may be used for assessment of project viability, cost, and duration, the approach that is expected to achieve the proposed objectives (200 words maximum).

Check all that apply: Lab testing , Computations ■ , Surveys , Field testsAnalyses and modeling ■ , Validation efforts ■ Other (obtaining and processing weather data) ■

Task 1. Conduct literature review of potential methods to correct biases in reanalysis data, focusing on their complexity and reported accuracy. The purpose is not to select *apriori* the best method, but to insure that other simple approaches have not been overlooked. Determine the most appropriate reanalysis model/models to use for the project.

Task 2. Research and determine the most appropriate surface observational data sets to use for the project. This will include hourly, daily summary, monthly summary, and monthly climate normals for US and global stations. Though we will not prescribe the data sets to use, we anticipate that the Integrated Surface Data (ISD), Global Historical Climate Network (GHCN) – Daily and Monthly will be included, along with WMO Climate Normals. Other data sets such as Global Summary of Day may also be used. Obtain the selected data for a minimum of 20 years for at least: 1) ten US/Canadian states and provinces including coastal, mountainous, inland, rural, and urban areas; and 2) ten non-US/Canadian countries including coastal, mountainous, inland, rural and urban areas. Note that the 20-year period of record does not apply to Climate Normals, which generally encompass a 30-year period. Preference should be given to countries with poor weather data availability, such as in Africa, South Asia, and Latin America. Sparse data is defined as those not meeting the criteria of data completeness for calculating design conditions or creating hourly weather files, e.g., less than 120 records per month and/or with extended data gaps.

Task 3. Obtain the corresponding reanalysis data and four downscaled WRF datasets (Weather Research Forecast as available) for the same locations and time periods. ASHRAE can provide the downscaled data from 1561-RP for four regions (Denver, San Francisco, Florida, and New York) for one year, although other downscaled data sets of longer time periods may also be publicly available for those locations and time.

Task 4. Utilizing all types of available data, develop a method/methods to bias-correct the reanalysis data for the following five weather parameters: dry bulb and dew point temperature, pressure, wind speed and direction. With time series data such as max/min values, the corrections can be done on a daily basis. Note that selection of "method/methods" may depend upon the combinations of source data (e.g. hourly, daily, monthly) available for the location.

Task 5. As a validation method, select a subset of locations with full hourly data available, and create from them a "sparse data equivalent" to the other locations in each set - e.g., reduce the hourly weather file to max-min values, and then use those artificial sparse data to bias-correct the corresponding reanalysis data. Comparison of the results to the actual hourly record could then be used to determine the accuracy of the corrected reanalysis data.

Task 6. Finalize the method/methods developed above to create: 1) A 20-year set of hourly data for multiple locations in each of the ten selected non US/Canadian countries along with the ten selected US/Canadian locations; 2) a set of Handbook Chapter 14 climate design tables for locations not currently available in Chapter 14 (from RP-1847). Note that this will be considered a "Tier 2/Class 2" level of stations with estimated values and may not include all of the parameters in the standard table. The methodologies and source code can then be used in the future to provide estimated hourly data and design data for many locations not currently available.

<u>Deliverables</u>:

a. Technical Deliverables

Task 1:

Report to the PMS regarding the research completed, the available methodologies in the literature, and the reanalysis model(s) selected.

Task 2:

Report to the PMS regarding the surface observational data sets selected, the available locations with measured data, the completeness and number of variables in the data. This report will include the reasoning behind the selection of each data set and any issues found.

Task 3:

Report to the PMS regarding the reanalysis data and downscaled (WRF) data obtained. Note that the downscaled data may be computer generated as part of the overall effort.

Tasks 4-5:

Technical report describing: 1) the method/methods to bias-correct the reanalysis data for: dry bulb and dew point temperature, pressure, wind speed and direction; 2) the results of the validation process. The initial report will be provided to the PMS, with a final report at project conclusion. This report will describe in detail how each of the surface observational data sets are used, the pros and cons, etc. It will also provide a detailed set of statistics regarding the accuracy of the data vs. measured hourly data – by location, region, season, and time of day.

Task 6.

a. Technical report describing the selected bias-correction method(s) including how missing data and parameters are produced, the construction of the artificial sparse data sets from the full data, and error analysis of the bias-corrected reanalysis data against the full data sets.
b. ASHRAE HOF formatted data tables of design conditions and hourly weather files in digital format.

b. Progress and Financial Reports

Progress and Financial Reports, in a form approved by the Society, shall be made to the Society through its Manager of Research and Technical Services at three quarterly intervals; specifically on or before each January 1, April 1, June 10, and October 1 of the contract period.

Furthermore, the Institution's Principal Investigator, subject to the Society's approval, shall, during the period of performance and after the Final Report has been submitted, report in person to the sponsoring Technical Committee/Task Group (TC/TG) at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

c. Final Report

A written report, design guide, or manual, (collectively, "Final Report"), in a form approved by the Society, shall be prepared by the Institution and submitted to the Society's Manager of Research and Technical Services by the end of the Agreement term, containing complete details of all research carried out under this Agreement. Unless otherwise specified, six copies of the final report shall be furnished for review by the Society's Project Monitoring Subcommittee (PMS). Following approval by the PMS and the TC/TG, in their sole discretion, final copies of the Final

Report will be furnished by the Institution as follows:

- An executive summary in a form suitable for wide distribution to the industry and to the public.

- One unbound copy, printed on one side only, suitable for reproduction.
- Two copies on CD-ROM; one in PDF format and one in Microsoft Word.

d. Technical Paper

One or more papers shall be submitted first to the ASHRAE Manager of Research and Technical Services (MORTS) and then to the "ASHRAE Manuscript Central" website-based manuscript review system in a form and containing such information as designated by the Society suitable for presentation at a Society meeting. The Technical Paper(s) shall conform to the instructions posted in "Manuscript Central" for a technical paper. The technical paper title shall contain the research project number 1900-RP) at the end of the title in parentheses, e.g., (1900-RP).

e. Data

Data is defined in General Condition VI, "DATA"

All papers or articles prepared in connection with an ASHRAE research project, which are being submitted for inclusion in any ASHRAE publication, shall be submitted through the Manager of Research and Technical Services first and not to the publication's editor or Program Committee.

f. Project Synopsis

A written synopsis totaling approximately 100 words in length and written for a broad technical audience, which documents 1. Main findings of research project, 2. Why findings are significant, and 3. How the findings benefit ASHRAE membership and/or society in general shall be submitted to the Manager of Research and Technical Services by the end of the Agreement term for publication in ASHRAE Insights.

The Society may request the Institution submit a technical article suitable for publication in the Society's ASHRAE JOURNAL. This is considered a voluntary submission and not a Deliverable. Technical articles shall be prepared using dual units; e.g., rational inch-pound with equivalent SI units shown parenthetically. SI usage shall be in accordance with IEEE/ASTM Standard SI-10.

Level of Effort

The project is planned to have 18-month duration (spread over 3 society meetings) with an approximate budget of $90,000.

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
	Task 1	**2**
	Task 2	**5**
	Task 3	**7**
	Task 4	**11**
	Task 5	**13**
	Task 6	**18**

Proposal Evaluation Criteria

Proposals submitted to ASHRAE for this project should include the following minimum information:

No.	Proposal Review Criterion	Weighting Factor
1	Contractor's understanding of Work Statement as revealed in proposal	15%
2	Quality of methodology proposed for conducting research	25%

3	Contractor's capability in terms of facilities and relevant prior research	20%
4	Qualifications of personnel for this project	15%
5	Probability of meeting the objectives and schedule of the Work Statement	25%

References

1. Balcomb, JD 1999. WeatherMaker User Manual, National Renewable Energy Laboratory, Golden CO.
2. Bradshaw, L. S. and Salazar, L. 1985. "On Using a Fourier Series Model for Estimating Diurnal Temperatures at Mountainous Locations in the Western United States", Journal of Climate and Applied Meteorology, Vol. 24, No. 10, October, pp.1104-1106.Degelman, L. 2004. "Simulation and uncertainty: weather predictions", *Advanced Building Simulation,* (Malkawi and Augenbroe, Ed.), Spon Press, New York and London, Chapter 3, pp 60-86.
3. Degelman, L. 1991. "A statistically-based hourly weather data generator for driving energy simulation and equipment design software for buildings", *Proc. Building Simulation '91*, International Building Performance Simulation Assoc. (IBPSA), 20-22 Aug., pp 592-599.
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6. Hansen, J.E. and Driscoll, D.M. 1977. "A Mathematical Model for the Generating of Hourly Temperatures", Journal of Applied Meteorology, Vol. 16, September, pp. 935-948.
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10. Qiu, X, M. Roth, H. Corbett-Hains, and F.Q. Yang 2016. "Mesoscale climate modeling procedure development and performance evaluation", Final report for RP-1561, ASHRAE, Atlanta GA.
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13. TC 4.2 2011. "WS-1494 Procedures to generate hourly climatic data from sparse data sets", submitted to ASHRAE Research Administration Committee.