Statistical adaptation of COSMO-7 predictions & their impact on predictive control of indoor building climate

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Introduction & Motivation

With the continuous improvement of numerical weather prediction (NWP) models and the ongoing increase of computational power, the range of applications making use of NWPs is expanding and includes industrial and decision making sectors. In particular, the availability of NWPs at a certain location for several days ahead enables anticipatory planning and/or the deployment of intelligent technologies in order to save limited resources. This in turn reinforces the need for accurate weather predictions at point locations. However, NWP models are area averaged predictions and diverge systematically and stochastically from the observed conditions at the location in question. Statistical downscaling methods have been developed to derive systematic relationships between time series of NWP model outputs and local observations.

We will focus on three model output parameters of the limited area mesoscale NWP model COSMO (Consortium for Small Scale Modelling, www.cosmo-model.org) that are of particular importance for the building automation. Hourly observations are used to adapt the NWP predictions to the local conditions. Within the research project OptiControl, the potential of using weather forecasts in different building climate control applications is being investigated for various building types and technical installations, locations and comfort requirements. Here, we show first results of a comparative simulation study for the application "Integrated Room Automation" (IRA) that allows us to quantify the benefit of NWP corrections in terms of primary energy savings for the predictive control of the indoor climate.

Prediction Error Models & Forecast Correction

The prediction error from past MeteoSwiss operational COSMO-7 forecasts (7km spatial resolution) and meteorological observations are used for the derivation and evaluation of the local corrections. The errors of the three weather parameters investigated (2m temperature TA, dewpoint temperature TD and global radiation GLOB) are functions of the direct model outputs (DMO) themselves, indicating a systematic bias. However, the statistical properties of the errors and the shape of these functions are different. Therefore, two algorithms are developed to correct future predictions.

2m Air & Dewpoint Temperature

The prediction errors of 2m TD and TA are characterised by a linear function of *T*. Temporal changes of this linearity (Fig. 1), e.g. due to unexpected weather changes, seasonal differences or, to some extend, nonlinearities are estimated recursively using a least squares estimation procedure based on a Kalman filter algorithm (Persson, WMO report series 34, 1991) assuming a random walk for the temporal evolution of the regression coefficients, i.e.

$$\hat{err}_T(t) = x_1(t) + x_2(t) \cdot T_{DMO}, \quad x_i(t+1) = x_i(t) + \xi_i(t), \qquad \xi_i(t) \sim N(0, \sigma_{x_i})$$

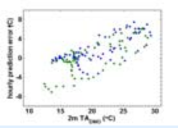


Fig. 1: Relationship between the hourly forecasted TA and the prediction error. 72h from 16. (blue) and 17.05.2006 at Lugano.

Global Radiation

The prediction error of GLOB predictions are dominated by the high temporal and spatial variability of the cloud cover that is not resolved in COSMO. As a result, the error is very noisy and highly skewed (Fig. 2). To correct for the systematic deficiencies (see Fig. 5) piecewise third order polynomials (splines) with three nodes are estimated from a gliding window of 2 months of past data using nonlinear least-squares optimisation. To account for the daily cycle, the splines are estimated for each hour of the day (*hod*).

$$\hat{err}_{GLOB} = f\{GLOB_{DMO}, t, hod\}$$

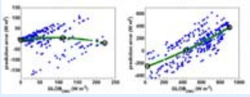


Fig. 2: Relationship between the forecasted GLOB and the prediction error. Shown are spring predictions for Basel at 7 UTC (left) and autumn predictions for Kloten at 12 UTC (right, blue DMO, green corrected predictions, nodes in circles).

Results & Verification

The performance of the two correction methods (PP) is evaluated by means of the seasonal systematic bias (mean error, ME) and the associated standard deviation of the error as a function of lead time. They are compared to the DMO and a persistence forecasts from observations of the past day. The corrections are successful and can be applied to locations where observations are available. Here, we show the results for selected sites to illustrate their effects on the NWP predictions. Not surprisingly, the persistence forecast on average is biasfree with larger associated uncertainties.

2m Air & Dew Point Temperature

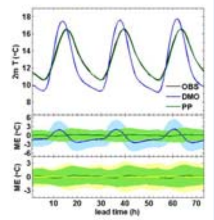


Fig. 3: Mean annual predictions (upper panel), their errors (bottom panels bold lines) and its standard deviation (light patches) for TA at Lugano, Switzerland for 2006.

The distinct diurnal cycle of the TA prediction error is illustrated in Fig. 3. The Kalman filter corrects for this bias and, at times, reduces the uncertainty in the predictions. Note that todays COSMO-7 version has an improved 2m TA diagnostic that corrects for this time shift. Fig. 4 shows that the error of the corrected TD forecasts increases with lead time indicating fast changing error characteristics being not entirely accounted for in the applied correction.

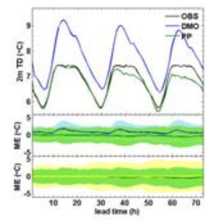


Fig. 4: Same as Fig. 3 for annual TD predictions at Clermont-Ferrand, France for 2006.

Global Radiation

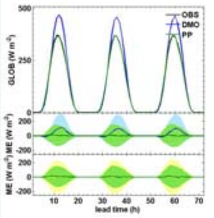
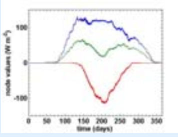


Fig. 5: Same as Fig. 3 for annual GLOB predictions at Kloten, Switzerland for 2006. Note, that this site has a particularly large bias not observed at most other stations.

For all sites, the error has a distinct daily cycle and is largest in spring and summer (Fig. 5 for the entire year). The presented spline correction removes the systematic deviations where necessary and, in places, also reduces the uncertainty in the predictions. An example for the changes in the nodes values over the year are shown in Fig. 6. The estimates are well defined and a clear annual cycle is typical for all investigated sites and hours of the day.

Fig. 6: Temporal evolution of the node values for 6 UTC at Kloten for 2006. Shown are the 95% confidence intervals for the values of the lowest (red, for 0<GLOB<10 Wm^{-2}), the middle (green, for 0<GLOB<110 Wm^{-2}) and the highest node (blue, for 0<GLOB<226 Wm^{-2}).



Application: Integrated Room Automation (IRA)

Within OptiControl (www.opticontrol.ethz.ch) IRA is one building control application of interest that has been investigated particularly thoroughly. Its scope is to simultaneously control heating, cooling and lighting in a single building zone (e.g., an office room) such that the room temperature and luminance levels stay within suitable, prescribed comfort ranges. Other applications as well as different novel control strategies are being investigated in the course of the project in order to locate and quantify the potentially added value of predictions.

The control variables are heating power delivered by radiators via a heat pump; cooling power delivered by a cooled ceiling via a mechanical chiller or via a wet cooling tower in free cooling operation; blind position; and artificial lighting power.

We used one year of hourly simulations of a dynamical building model with different weather forecasts to estimate annual total primary energy consumption (PEC). The control variables were updated every hour based on a Model Predictive Control (MPC) algorithm that incorporated weather forecasts for 32 hours ahead. The benefit of using MPC for IRA lies in particular in the predictive determination of blind positioning and of free cooling usage (both associated with low PEC) such that the energy intensive usage of the heat pump and the mechanical chiller is minimized.

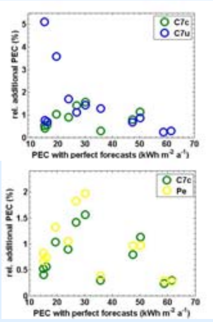


Fig.7: Additional PEC simulated under the three different weather forecast methods compared to the PB (perfect predictions). The results were highly case dependent. On average, the use of C7c vs. C7u lead to lower PEC increments, while the impact of using Pe or C7c on PEC was similar.

The meteorological parameters used by the controller were GLOB (on the vertical orientations of the buildings), TA, and TD (derived from dew point and TA).

Four building types with one technical installation at three different locations (Kloten, Basel, Marseille) are considered.. For each case, the lowest possible PEC ("Performance Bound", PB) was estimated by an MPC procedure with perfect knowledge of the building's dynamics and the availability of perfect weather and internal gains forecasts. The results of the PB simulations were then compared to those from simulations using COSMO-7 DMO (C7u, elevation correction only); COSMO-7 output with the above presented corrections (C7c); and a persistence forecast (Pe, "same weather as past day").

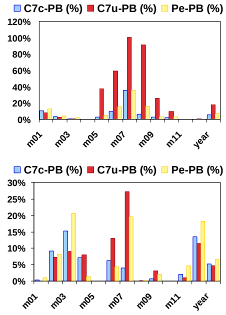


Fig. 8: Examples of monthly PEC increments relative to the monthly PB values. Results are given for office rooms with "Swiss average" thermal insulation levels and south orientated façades at sites Marseille (upper panel) and Kloten (lower panel), respectively. The differences exhibited distinct annual cycles. This result was typical for all cases (not shown).

Conclusions

Systematic errors of COSMO-7 point predictions can be removed by statistical adaptations

Correction of forecasts can help reducing PE consumptions in IRA applications although persistence performs similar

More impact of weather forecasts on the energy efficiency or comfort can be expected when looking at other building automation applications, i.e. active storage management or systems with strongly weather-dependent energy supply